Mapping Habitats by Integrating Multi-Source Land Use Land Cover Databases: Application to Red Fox in Urban Area

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Keywords: Habitat, Fox, Urban, Mapping, LULC, GPS.

Abstract: Habitats are key components for understanding wildlife space use. Having access to an accurate description of habitats can contribute to conservation programs and help define optimal landscape planning projects. In this study, we focus on the study case of red fox in a French urban environment. Our approach was to describe and to map habitats at a detailed spatial scale based on existing and available multi-source geographical databases. An automatic mapping process was proposed and then applied on the study site. The computed map was assessed based on a ground truth: depending on the land covers, the precision was good, between 69% and 94%. A GPS location dataset of red fox individuals were analysed with respect to the proposed map. Results showed consistent space use between the GPS locations and literature. They highlighted that separating land cover from land use is beneficial to consider the influence on red fox of both landscape features and their anthropic uses. The opportunity of the proposed automatic process is to be able to map habitats regarding the ecological functions of the landscape, in various environments and at different dates.

1 INTRODUCTION

Loss of habitats and their degradation are major causes of wildlife endangerment, particularly in terms of loss of species richness, decrease in population size and damage to the health and welfare of individuals (Paiva et al., 2020; Béchet et al., 2017). As part of their ecosystems, animals are related to the environment they live in. They influence their environment by contributing to its functioning (interspecies interactions, predation and flow of matter through their movements) and depend on it (Flockhart et al., 2014). Natural environments have been modified by humans with varying degrees of intensity (Magle et al., 2010). Urban environments are specifically highly modified and urbanization processes leads to rapid changes (Torre et al., 2017; Li et al., 2006). At the same time, wildlife is present and tends to return into cities, supported by reservoirs such as green spaces and corridors such as linear transport infrastructures (Janko et al., 2012; Ethier & Fahrig, 2011; Sorace & Gustin, 2009). Urban environments are moreover high-stake economic and planning areas, making them strategic for conservation policies.

Understanding the spatial dynamics of fauna requires an accurate and meaningful description of their habitats (Li et al., 2014; Jantz & Goetz, 2008). A habitat can be defined as a part of space which is composed of interrelated environmental factors and which corresponds to relatively homogeneous life conditions (Boullet, 2003; Whittaker et al., 1973). They are described by the composition and the structure of the landscape besides the biocenose (Burel & Baudry, 1999). Ad hoc located information can be collected in the field or by remote sensing, which is often time-consuming (Crawley et al., 2021). It can be extracted from existing databases

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Jolivet, L., Robardet, E. and Cohen, M.
Mapping Habitats by Integrating Multi-Source Land Use Land Cover Databases: Application to Red Fox in Urban Area.
DOI: 10.5220/0012631800003696

In *Proceedings of the 10th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2024)*, pages 136-143
ISBN: 978-989-758-694-1; ISSN: 2184-500X

(Ruf et al., 2018). Several programs aim at mapping habitat. The French program CarHAB planned by 2025 focuses on the characterization of vegetation. Other programs target landscape features identified for their ecological interest: the Street Tree Layer in Urban Atlas from Copernicus, open data on hedgerows in the Netherlands, the MOS, Ecomos and Ecoline maps in the Île de France region.

Our hypothesis is that existing geographical databases not dedicated to the description of habitats contain rich information to map wildlife-relevant aspects. Information already compiled into available databases may be capitalized and ad hoc data collection minimized, albeit each database results from dedicated specifications and application goals (Taylor et al., 2018). Benefit is also to be able to work on various study cases associated to specific study field and species and at different dates. Our approach is to propose a process to map favourable or less favourable habitats for a species or a group of species by integrating physical descriptions of space as well as anthropic uses. A habitat is considered as favourable when offering hiding places, shelters, food resources and relative distance to humans.

Our objective in this work is to compute a habitat map adapted to the study case about red fox habitats. The contributions of the work are an automatic habitat mapping process taking as inputs available geographical databases, a nomenclature of land cover and a nomenclature of land use based on the INSPIRE nomenclature, an assessment of the produced map, then the analysis of red fox GPS data from the map. In the first part of the article, we present the study case, the relevant existing databases and our strategy to map habitats. In the second part, the mapping process is implemented and applied for the study case. The map is evaluated in regard to several criteria. In the third part, the resulting habitat map and its potential applications and perspectives are discussed.

2 MATERIAL AND METHODS

2.1 Case Study of Red Fox in Urban Area

The study site is the *Métropole du Grand Nancy* in the north-eastern France (140 km², 255.000 inhabitants in 2020, source: INSEE). The environment is continuously urbanized, between the historical centre of Nancy and its outskirts, though it contains densely urbanized parts and low-urbanized parts with scattered buildings and wooded land, surrounded by forested and agricultural lands. The site is consequently harbouring various types of land use and landcover in relatively small surface areas.

Red fox is a generalist medium-size species and can be encountered in urban areas (Reshamwala et al., 2021). It is classified by decree as liable to cause damage and is not protected. GPS tracking data were carried out on red foxes (*Vulpes vulpes*) within the study site in order to monitor zoonotic diseases (Robardet, 2007). GPS data of eight foxes were recorded in 2006 and 2007. Each individual was tracked for an average of two months, mainly during autumn and winter. The frequency of the GPS locations is four hours in continuously and five minutes during five distinct days. Position accuracy is estimated at around 20 meters. A total number of 1200 points was actually recorded.

2.2 Input Multi-Source Databases

Input data of the targeted habitat map are freely available geographical databases from the French national geoservices.ign.fr platform and the European Copernicus program as described in Table 1. BD TOPO, BD Forêt and RPG contain respectively anthropic, wooded and agricultural features. CORINE Land Cover is a LULC database. BD PARCELLAIRE describes cadastral parcels. The geographical entities are polygons (e.g. buildings), lines (roads) and points (water tower). We selected the most contemporaneous databases to the red fox GPS data: 2007 versions of the databases and the 2006 version of CORINE Land Cover. To complete the description, there are one Natura 2000 area, one biotope decree and five natural area of ecological, faunistic and floristic interest (ZNIEFF).

Table 1: Spatial, temporal and semantic (number of items in nomenclatures) characteristics of the input databases.

Source	Mapping unit, scale	Update	Number of items
BD TOPO	500 m² for woods, 1/5000 m scale	continuously	45
BD PARCEL - LAIRE	1/5000 m scale	continuously	0
BD Forêt	5000 m² and at least 20 m wide	three years	32
RPG	1/5000 m scale	every year	28
CORINE Land Cover	0.25 km²	six years	4

2.3 Specifications of the Habitat Map

The targeted habitat map contains adjacent polygons so that spatial description is continuous and provides information at every point in the space. The spatial scale of the map should be consistent with the extent of landscape used by the red fox. The studied red foxes have a corresponding home range of around 1 km² and travel a daily distance from 5 to 10 km, especially at night. The map should be applicable for urban, suburban and periphery areas as foxes roam in these various types of environment.

The semantic content is structured with respect to a nomenclature differentiating land cover and land use (Comber, 2008). It is based on the recommendations from the French council for geo-localized information (CNIG), which is also the foundation of the nomenclature of OCS GE available on specific French regions. Land cover is the physical description of the space and corresponds to living space and resources for animals. Land use is the anthropic use and may induce opportunities or disturbances.

2.4 Cartographical Process

The proposed strategy to compute the geographical objects of the habitat map targets an automatic process. Automatic computation follows a data integration process. Similar cartographic processes have been implemented in the French blue-green infrastructure program *Trame Verte et Bleue* (Amsallem et al. 2010). The geometries of the geographical objects result from operations of intersection, merging and selection. First, we defined a hierarchical order among the input sources so that the objects on a detailed scale (e.g. the polygon of a building from the BD TOPO) cut the objects of small scale (e.g. the polygon of CORINE Land Cover encompassing the polygon of the building). Second, line geometries in the data sources are changed into polygons with a buffer of estimated width based on existing attributes values. Third, point geometries are not taken into account, only their attribute values are. Finally, allocation of a land cover item and a land use item fetches the semantic values from the inputs sources that were beforehand reclassified according to our nomenclature. Each polygon inherits of the semantic values from all its input sources (e.g. the house inherits from the values in BD TOPO and in CORINE Land Cover). The numerical computation was undergone in Python and cartographic display in QGIS.

2.5 Assessment

Automatic allocation of items was carried out based on the input databases. The assessment of the map focuses on specific landscape elements selected due to their relevance in ecology: land cover items of transport lanes, land cover items of the borders of cadastral parcels and the geometry of the tree vegetation polygons. A ground truth was obtained by visual interpretation of complementary sources: aerial images taken in 2009, Google Street View and in situ observations. The computation was done in Python, according to a Monte-Carlo strategy i.e. a random selection of map features to be assessed (Healey et al., 2014).

For the transport lanes, car lanes were automatically allocated with the land cover item *concrete road network* and other lanes with the land cover item *other mineral or composite material ground*. The assessment dataset contains 100 objects of car lanes and 100 of other lanes. For the borders of cadastral parcels, they were assumed to match with physical limits and automatically allocated with the land cover item *other concrete area* which can be with or without vegetation. The assessment dataset is of 100 borders. Regarding the tree vegetation, 100 points of tree cover and 100 points of non-tree cover were sampled in the habitat map, then validated or not. In addition, 100 tree vegetation polygons were digitized.

3 RESULTS

This section present the results regarding the definition of the nomenclature differentiating land cover and land use, the implementation of the cartographical process resulting in the habitat map and the assessment of the map. Then the proposed habitat map is put into perspective with the study case of red fox habitats.

3.1 The Defined Nomenclature

For land cover, 14 items were defined in level 1, 25 items in level 2 and 35 items in level 3. In level 1, there are three items for concrete areas, three for soil type, one about cropland, one for water, five about vegetation types and one unknown cover in case no assignment could be made. The land cover nomenclature is flat except for the tree formation item which is detailed at levels 2 and 3 based on the input source BD Forêt. We strove to structure all items so that the map would be meaningful even at the level 1 which is the coarsest. For instance, concrete road network was differentiated from built-up concrete area and other concrete area including sidewalks due to the specific composition of each of the land covers (e.g. guardrails and signs for roads; houses and sheds for built-up areas; benches and shelters for sidewalks). For most of the items at level 1, little information could be extracted from the input sources that would have enabled to detail the levels 2 and 3. This is more specifically due to the thematic content of the input databases (e.g. no distinction between different road surfaces or different croplands), to their spatial scale (e.g. linear objects like fences that are thinner than the minimal spatial units) and to their goals and applications (e.g. no relevance in distinguishing types of roofs).

For land use, 21 items were defined in level 1, 44 items in level 2 and 76 items in level 3. The nomenclature for LU contains more items than for LC because there are more detailed descriptions about anthropic uses than about covers in the input databases. Land use items at level 1 about transport and about residential, industrial or specific buildings are the most detailed at levels 2 and 3. Even if the choice was made to distinguish uses from covers, we also aimed at maintaining information that is locally relevant for the description of habitats and meaningful for animal studies. Besides, buildings strongly structure the environment, specifically in urbanized areas. Keeping the distinction for similar uses between built and other covers provides a map that can be more easily interpreted and better suited for understanding and studying animal space use and movements. We therefore deemed it appropriate to maintain some cover content in land use items, in particular, when a use can be associated with very different land covers. Consequently, items at level 1 were split depending on their built or unbuilt covers. The cadastral boundaries were specifically used to define the item *private gardens*.

3.2 Output Database and Map

The cartographic process corresponds to the geometrical operations leading to new polygonal objects by supplementing them with a cover item and a use item from the defined nomenclature for the habitat. The final map in the Nancy study site contains approximately 230,000 polygons with the cadastral borders and 70,000 polygons without them. An extract of the map is illustrated in Figure 1. For the same geographical extent, the objects are alternately colour-coded with land cover and with land use items.

The area in Figure 1 is composed of a public square, of a riding centre and sport ground, of private residential parcels, of a commercial and industrial area, surrounded by road and rail transport lines. Vegetation cover corresponds alternatively to industrial, residential or local ecological use and build cover corresponds to private houses, public buildings for sports and recreation.

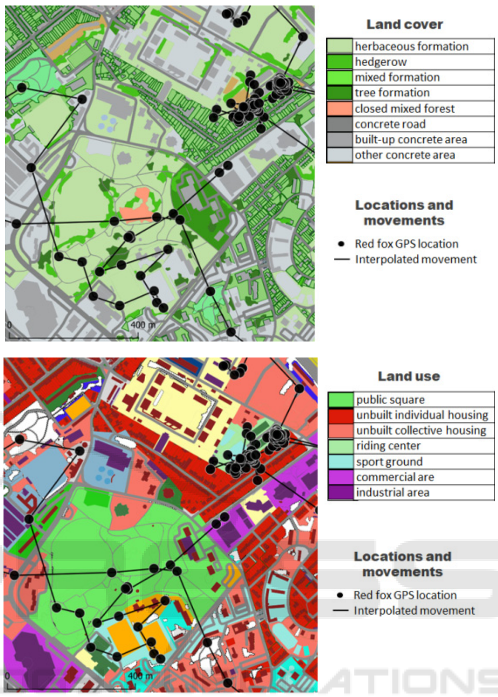

Figure 1: A zoom in the study area in the *Métropole du Grand Nancy* with red fox locations and habitats described by land cover and land use items at level 3. Cadastral borders are displayed only in the residential gardens.

3.3 Assessment

The first assessed criterion is the land cover of the transport network including car traffic lanes (76% of the map database objects) and lanes dedicated to other transport modes such as cycling or walking (24%). We found 94 (with +/- 2.4 uncertainty) % of car lanes and 84 (+/- 3.7) % of other lanes accurately assigned. The other lanes incorrectly assigned correspond in majority to concrete cover or low vegetation. Car lanes are related to risks of collision for wildlife and to high disturbance such as for small fauna sensitive to cover (Marsh et al., 2005). Lanes for other transport modes are also interesting for the description of habitats because they generally mean less impact and animals can use them unimpeded.

The second assessed criterion is about the land cover of cadastral borders. Results are that 31 (+/-

4.6) % of borders were built-up (fences, walls, house edges), 38 (+/- 4.9) % were vegetation (mainly hedgerows, with or without built-up elements) and 31 (+/- 4.6) % did not correspond to a physical limit (e.g. in the middle of a lawn). 69% of cadastral borders corresponded then to a physical limit and may be associated with an ecological function of obstacles or of shelter places. This characterization is interesting to provide indication about located favourable elements such as hedgerows and to determine an overall landscape connectivity (Nogués & Cabarga-Varona, 2014; Lecq et al., 2018).

The last criterion regarding the tree vegetation resulted in a precision equal to 81 (+/-3.9) % for tree cover points, and to 94 (+/- 2.7) % for non-tree points. Thus 87.5% of the red fox GPS locations may be assumed as rightly included in a tree or in a non-tree cover. The total area of tree vegetation polygons was equal to 17.29 ha in the map and to 13.94 ha in the ground truth. The general union is 19.63 ha and the intersection 11.38 ha. These differences can be partly explained by the specifications of the input databases that do not include all tree cover areas especially small ones. The results indicate an overestimation in our map of tree cover, thus of potential habitats favourable including resources and protection for animals in the study site.

3.4 Study of Red Fox Habitat

The presence of red fox in each different habitat described in the map was characterized. Percentages of individual locations were computed with respect to land covers and uses. A dataset of GPS points was extracted; it corresponds to a monitoring during one day of four foxes with a five-minute frequency. These tracks describe individual movements. They enable to consider habitats in home ranges (estimated based on the complete monitoring) and habitats crossed briefly.

Table 2: Percentages of GPS points of four red foxes included in the land covers and uses mainly travelled.

Land cover item	**% of red fox points**	**Land use item**	**% of red fox points**
Herbaceous formation	24%	*Culture, leisure*	35%
Hedgerow	22%	*Unbuilt residential land*	25%
Tree formation	17%	*Agriculture*	13%
Mixed formation	16%	*Sport*	12%
Built-up concrete area	7%	*Transport and industrial built area*	7% each

The spatial analyses in Table 2 tend to indicate proximity to residential or public buildings with nearby vegetation in private gardens or public green spaces. Agriculture and wooded land were also used, especially for individuals living at the edge of the urban built area. In this urbanized environment, the most used habitats appear to be the different vegetation formations, with herbaceous, hedgerow, tree and mixed vegetation types. To synthetize, items with most locations contained low or high vegetation features and corresponded to relatively moderate human occupancy.

4 DISCUSSION

Our cartographic workflow and resulting map can be put into perspective by comparing them with existing approaches for mapping natural habitats. The major constraint of our approach is the availability of input geographical databases. It is however an interesting aspect because it enables to extract relevant information for habitats without duplicating data collection. It is the combination of multi-source information that adds value to the description of habitats for animal's species. Another interesting aspect is the distinction between the physical description of habitats and associated anthropic uses. The published OCS GE database in some regions of France contains the distinction between land cover and land use at detailed spatial scales, which brings valuable information. The scale is adapted for monitoring soil sealing for local public authorities. When designed for habitats favourable or not for animal species, the description can be completed from other databases with a more detailed spatial scale, e.g. containing building footprints, or with more detailed attribute values, e.g. on tree formations. It is difficult to compare the EUNIS habitat map and our map, because the former is on a European scale and its spatial resolution is large. The distinction between vegetation types in our map is not as precise as expected in the CarHAB project. In our map, the nomenclature items involve different types of forest stands and undergrowth vegetation. It is suitable for describing habitats in urbanized environments and this information is available in the existing databases. We did not focus on vegetation only, but also on other habitats that could potentially be used by animals in urbanized environments. Vegetation items can be mixed with other cover elements; for instance urban green areas are commonly public parks and residential gardens and can be combined with infrastructures like paths, terraces, small shelters, etc. These habitats can sometimes be difficult to qualify as favourable, or not, but can be identified as used or not by animals.

The results about the study case are consistent with knowledge about the habitat of urban red fox. Green spaces in urban areas are related to spatial preferences (Rosatte & Allan, 2009; Robardet, 2007). The use of hedgerows is notable in agricultural land (Note & Poix, 2006), but can be consistent as well in more urbanized environment. Landscape features associated with human housing or activities are of interest as potential resources (Contesse et al., 2004) although quiet and hidden places like residential gardens are favoured for resting (Harris & Rayner, 1986). The analysed GPS datasets contain daily movements within the extent of home ranges. Some long-distance movements, such as exploratory movements may occur. In that case, crossed habitats are not necessarily considered as favourable though used as transit areas, like surroundings of railways (Trewhella & Harris, 1990) or commercial areas with intense human activities.

The extent of the proposed approach in other study sites is subject to the availability of input data sources and to their specifications, especially for limited spatial extents and spatially non-uniform collection specifications (Barrington-Leigh & Millard-Ball, 2017). The presented study case was about urban red fox. The targeted spatial scale of the map and the level of detail of the nomenclature appeared to be adapted to this species and in general to medium-sized animals that have home ranges of several square kilometres and travel a few kilometres a day. It would be interesting to apply the process in various environments and with other animal location data. For instance, animal species may travel and use their environment at different spatial scales with varying meaningful landscape features (Sánchez et al., 2014; Li et Wilkins, 2014; Fryxell et al., 2008; Le Corre et al., 2008). On-going work is about the temporal aspects, in particular the ability of providing time-snapshots of the habitat map. Time is important in the notion of habitat. Seasonal variations especially affect vegetation. The importance of vegetation for wildlife varies with growth stage for wildlife to feed on or to hide in. Infra-annual changes can be retrieved with remote sensing techniques (Gómez et al., 2016). Vegetation – and potentially all covers – changes over the years. Related anthropogenic uses vary over time, especially in growing suburbs. Being able to map these changes in habitats provides a means to study the consequences on animals at successive dates (Koteen, 2002; Cavallini & Lovari, 1991).

5 CONCLUSION

A habitat map was built to provide a relevant description of space and to support animal space use and movement studies. The starting point of this study was to determine if relevant habitat maps could be computed from existing multi-source geographical databases. We chose to keep the land cover distinct from the land use in the defined nomenclature as human activity may strongly influence the presence of animals especially in urban areas. A mapping process was implemented first to qualify existing databases and identify the relevant information, and second to retrieve the corresponding objects and fill in the nomenclature. Assessment of the map was carried out based on specific landscape features of potential functions for animals: roads, parcel boundaries and tree vegetation that may be obstacles, movement corridors or shelters. Tracking location of red fox were then analysed regarding the habitat map, which highlighted the relevancy of having access to land cover and land use information. The challenge is now to extend the mapping process to environments other than urbanized areas, and to animal species traveling on large or small spatial scales, or with specific space use and movement.

REFERENCES

Amsallem, J., Deshayes, M., & Bonnevialle, M. (2010). Analyse comparative de méthodes d'élaboration de trames vertes et bleues nationales et régionales. Sciences Eaux & Territoires, 3, 40–45. doi: 10.3917/set.003.0040

Barrington-Leigh, C., & Millard-Ball, A. (2017). The world's user-generated road map is more than 80% complete. PLOS ONE, 14(10). https://doi.org/10.1371/journal.pone.0180698

Béchet, B., Le Bissonnais, Y., Ruas, A., Aguilera, A., André, M., Andrieu, H., … Desrousseaux, M. (2017). Sols artificialisés et processus d'artificialisation des sols, Déterminants, impacts et leviers d'action. INRA France

Boullet, V. (2003). Réflexions sur la notion d'habitat d'espèce végétale. Fédération des Conservatoires Botaniques Régionaux.

Burel, F., & Baudry, J. (1999). Écologie du paysage. Concepts, méthodes et applications. Eds TEC & DOC, Paris

Cavallini, P., & Lovari, S. (1991). Environmental factors influencing the use of habitat in the red fox, Vulpes vulpes. Journal of Zoology, 223(2), 323–339. doi: 10.1111/j.1469-7998.1991.tb04768.x

Comber, A. J. (2008). The separation of land cover from land use using data primitives. Journal of Land Use Science, 3(4), 215–229. doi: 10.1080/174742308024 65173

Contesse, P., Hegglin, D., Gloor, S., Bontadina, F., & Deplazes, P. (2004). The diet of urban foxes (Vulpes vulpes) and the avaibility of anthropogenic food in the city of Zurich, Switzerland. Mammalian Biology, 69(2), 81–95. doi: 10.1078/1616-5047-00123

Crawley, M. J., Pakeman, R. J., Albon, S. D., Pilkington, J. G., Stevenson, I. R., Morrissey, M. B., Jones, O. R., Allan, E., Bento, A. I., Hipperson, H., Asefa, G., & Pemberton, J. M. (2021). The dynamics of vegetation grazed by a food-limited population of Soay sheep on St Kilda. Journal of Ecology, 109, 3988–4006. Ddoi: https://doi.org/10.1111/1365-2745.13782

Ethier, K., & Fahrig, L. (2011). Positive effects of forest fragmentation, independent of forest amount, on bat abundance in eastern Ontario, Canada. Landscape Ecology, 26, 865–876. doi: 10.1007/s10980-011-9614-2

Flockhart, D. T. T., Pichancourt, J.-B., Norris, D. R., & Martin, T. G. (2014). Unraveling the annual cycle in a migratory animal: Breeding season habitat loss drives population declines of monarch butterflies. Journal of Animal Ecology. doi: 10.1111/1365-2656.12253

Fryxell, J. M., Hazell, M., Börger, L., Dalziel, B. D., Haydon, D. T., Morales, J. M., … Rosatte, R. C. (2008). Multiple movement modes by large herbivores at multiples spatiotemporal scales. Proceedings of the National Academy of Sciences, 105(49), 19114–19119. doi: 10.1073/pnas.0801737105

Gómez, C., White, G. C., & Wulderc, M. A. (2016). Optical remotely sensed time series data for land cover classification: A review. ISPRS Journal of Photogrammetry and Remote Sensing, 116, 55–72. doi: 10.1016/j.isprsjprs.2016.03.008

Harris, S., & Rayner, J. M. V. (1986). Urban Fox (Vulpes vulpes) Population Estimates and Habitat Requirements in Several British Cities. Journal of Animal Ecology, 55(2), 575–591. doi: 10.2307/4740

Healey, S. P., Urbanski, S. P., Patterson, P. L., & Garrard, C. (2014). A framework for simulating map error in ecosystem models. Remote Sensing of Environment, 150, 207–217, doi: 10.1016/j.rse.2014.04.028.

Janko, C., Schröder, W., Linke, S., & König, A. (2012). Space use and resting site selection of red foxes (Vulpes vulpes) living near villages and small towns in Southern Germany. Acta Theriologica, 57, 245–250. doi: 10.1007/s13364-012-0074-0

Jantz, P., & Goetz, S. (2008). Using widely available geospatial data sets to assess the influence of roads and buffers on habitat core areas and connectivity. Natural Areas Journal, 28, 261–274. https://doi.org/10.3375/0885-8608(2008)28[261:UWAGDS]2.0.CO;2

Koteen, L. (2002). Climate change, whitebark pine, and Grizzly bears in the greater Yellowstone ecosystem. In: Schneider SH and Root T (Ed) Wildlife Responses to Climate Change: North American Case Studies, Island Press

Le Corre, M., Pellerin, M., Pinaud, D., Van Laere, G., Fritz, H., & Said, S. (2008). A multipatch use of the habitat: testing the First-Passage Time analysis on roe deer paths. Wildlife Biology, Nordic Council for Wildlife Research, 14, 339–349. https://doi.org/10.2981/0909-6396(2008)14[339:AMUOTH]2.0.CO;2

Lecq, S., Loisel, A., Mullinb, S. J., & Bonnet, X. (2018). Manipulating hedgerow quality: Embankment size influences animal biodiversity in a peri-urban context. Urban Forestry & Urban Greening, 25.doi: 10.1016/j.ufug.2018.08.002

Li, H., & Wilkins, K. T. (2014). Patch or mosaic: bat activity responds to fine-scale urban heterogeneity in a medium-sized city in the United States. Urban Ecosystems, 14(4), 1013–1031. doi: 10.1007/s11252-014-0369-9

Li, T., Shilling, F., Thorne, J., Li, F., Schott, H., Boynton, R., & Berry, A. M. (2006). Fragmentation of China’s landscape by roads and urban areas. Landscape Ecology.doi:10.1007/s10980-010-9461-6

Magle, S. B., Reyes, P., Zhu, J., & Crooks, K. R. (2010). Extirpation, colonization, and habitat dynamics of a keystone species along an urban gradient. Biological Conservation. doi:10.1016/j.biocon.2010.05.027

Marsh, D. M., Milam, G. S., Gorham, N. P., & Beckam, N. G. (2005). Forest Roads as Partial Barriers to Terrestrial Salamander Movement. Conservation Biology, 19(6). doi: 10.1111/j.1523-1739.2005.002 38.x

Nogués, S., & Cabarga-Varona, A. (2014). Modelling land use changes for landscape connectivity: The role of plantation forestry and highways. Journal for Nature Conservation 22(6), 504–515, doi: 10.1016/j.jnc.20 14.08.004

Note, P., & Poix, C. (2006). Simulations spatialisées des pullulations de campagnols terrestres : Étude de l'influence des structures paysagères. Cybergeo: European Journal of Geography. http://cybergeo. revues.org/3219

Paiva, P. F. P. R., de Lourdes Pinheiro Ruivo, M., da Silva Júnior, O. M., de Nazaré Martins Maciel M., Gleice Martins Braga T., Marília Nogueira de Andrade M., … Monteiro Ferreira B. (2020). Deforestation in protect areas in the Amazon: a threat to biodiversity. Biodiversity and Conservation, 29, 19–38. doi: 10.1007/s10531-019-01867-9

Reshamwala, H. S., Mahar, N., Dirzo, R., & Habib, B. (2021). Successful neighbour: Interactions of the generalist carnivore red fox with dogs, wolves and humans for continued survival in dynamic anthropogenic landscapes. Global Ecology and Conservation, 25, doi: 10.1016/j.gecco.2020.e01446

Robardet, E. (2007). Étude de la transmission d’Échinococcus multilocularis dans une grande agglomération : influence du comportement alimentaire et de l’utilisation de l’espace par le renard roux (Vulpes vulpes) sur la contamination de l’environnement. PhD Université Franche-Comté.

Rosatte, R., & Allan, M. (2009). The ecology of red foxes, Vulpes vulpes, in Metropolitan Toronto, Ontario:

disease management implications. Canadian Field-Naturalist, 123 (3):215-220, doi: 10.22621/cfn.v123i3.967

Ruf, K., Gregor, M., Davis, M., Naumann, S. and McFarland, & K., 2018. The European Urban Biodiversity Index (EUBI): a composite indicator for biodiversity in cities. ETC/BD report to the EEA.

Sánchez, M. C. M., Cushmanb, S. A., & Sauraa, S. (2014). Scale dependence in habitat selection: the case of the endangered brown bear (Ursus arctos) in the Cantabrian Range (NW Spain). International Journal of Geographical Information Science, 28(8), 1531–1546. doi: 10.1080/13658816.2013.776684

Sorace, A., & Gustin, M. (2009). Distribution of generalist and specialist predators along urban gradients. Landscape and Urban Planning. doi: 10.1016/j.landurbplan.2008.10.019

Taylor, J., Haines, A., Milner, J., Davies, M., & Wilkinson, P. (2018). A Comparative Analysis of Global Datasets and Initiatives for Urban Health and Sustainability. Sustainability, 10. doi: 10.3390/su10103636

Torre, C.M., Morano, P., & Tajani, F. (2017). Saving Soil for Sustainable Land Use. Sustainability, 9(3). doi: 10.3390/su9030350

Trewhella, W. J., & Harris, S. (1990). The effect of railway lines on urban fox (Vulpes vulpes) numbers and dispersal movements. Journal of Zoology, 221, 321–326. doi: 10.1111/j.1469-7998.1990.tb04004.x

Whittaker, R., Levin, S., & Root, R. (1973). Niche, Habitat, and Ecotope. The American Naturalist, 107(955), 321-338.