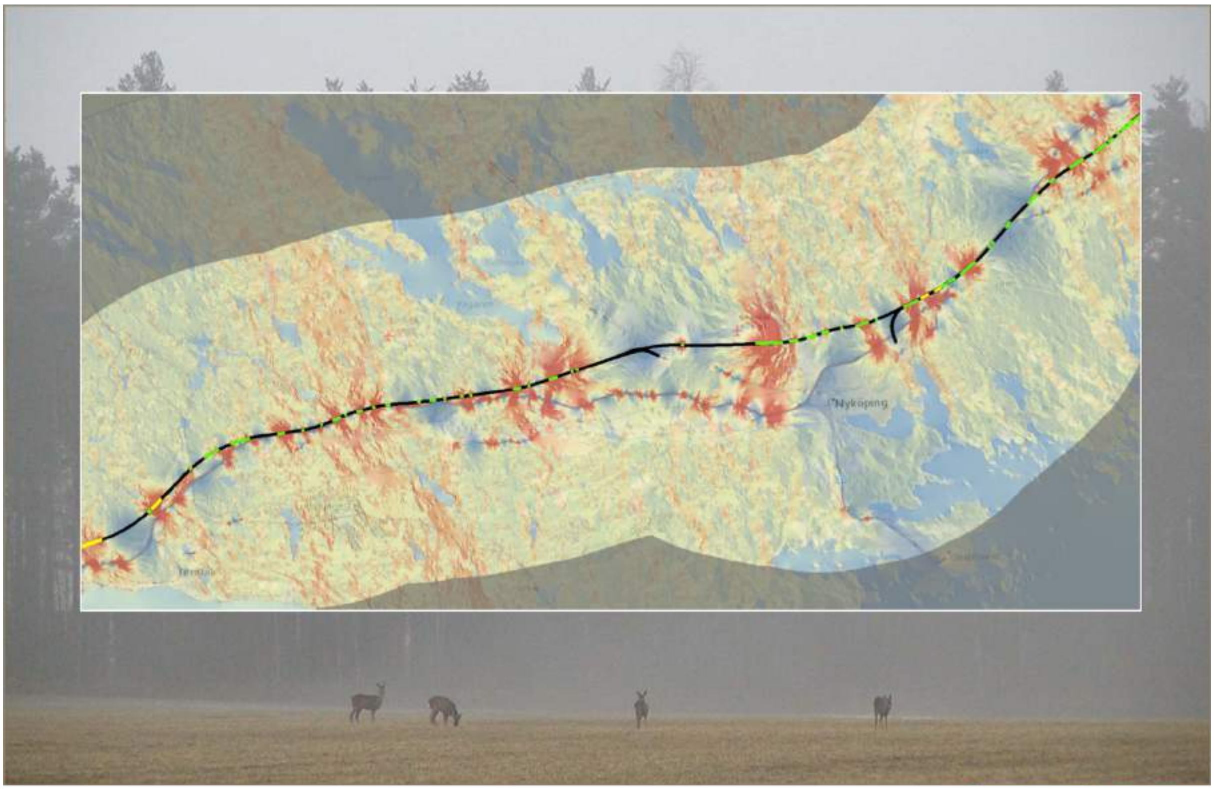

Wildlife movement simulation using circuit theory modelling

Description of methodology used for the planning of Ostlänken (OL) and Götalandsbanan (GLB) high-speed railways in Sweden

ABOUT THE REPORT:

Titel: Wildlife movement simulation using circuit theory modelling: Description of methodology used for the planning of Ostlänken (OL) and Götalandsbanan (GLB) high-speed railways in Sweden

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Contents

Summary in English

In order to find an objective basis for planning of wildlife measures in road and railway projects, in the last years the Swedish Transport Administration has supported the development of a method to model landscape connectivity for large wildlife in GIS based on circuit theory. The development has been conducted within a number of practical infrastructure planning projects. This report describes the modelling as developed and applied in the planning of Ostlänken and Götalandsbanan high-speed railways in south-central Sweden.

Movement simulations were done for moose *(Alces alces)* and roe deer *(Capreolus capreolus)*, as these are target species for wildlife measures in most Swedish road and railway projects, and can function as ”umbrella species” for other large wildlife. Literature data of species´ habitat preferences, infrastructure barrier effects and effectiveness of bridges as wildlife passages were translated into resistance values that was used as input data in simulations. A patch-free model was used, showing the flow of individuals between broader regions, i.e. with starting and ending points outside of the respective study area. Such a set-up is suited for illustrating connectivity on a wider landscape level (long-distance movements), and for species that are not concentrating in core habitats but are having diverse needs for habitat quality and quantity, as is often the case for large wildlife.

Tentative validations of the modelling results from Ostlänken were done by wildlife expert opinion and by comparing with data on wildlife road casualties. While wildlife experts gave an overall support to the modelling approach and output, there were little or no relation between simulated animal movements and wildlife accidents.

Further steps for method development and validity testing are suggested.

Sammanfattning på svenska

I avsikt att få fram ett objektivt underlag för planeringen av faunaåtgärder inom väg- och järnvägsprojekt har Trafikverket under de senaste åren stött utvecklingen av en metod för att modellera landskapskonnektiviteten för större viltarter i GIS baserat på kretsteori. Utvecklingen har genomförts inom ett antal praktiska infrastrukturplaneringsprojekt. I denna rapport beskrivs den utveckling och tillämpning som gjorts inom planeringen för höghastighetsjärnvägarna Ostlänken och Götalandsbanan.

Simuleringar av viltrörelser gjordes för älg och rådjur, eftersom dessa är målarter för faunaåtgärder i de flesta svenska väg- och järnvägsprojekt och kan fungera som "paraplyarter" för andra stora däggdjur. Litteraturdata på arternas habitatpreferenser, barriäreffekter av infrastruktur samt broars effektivitet som faunapassager översattes till motståndsvärden, vilka användes som indata i simuleringarna. I simuleringarna användes en modell utan kärnområden (s.k. patch-free model), som visar flödet av individer mellan regioner, dvs. med start- och slutpunkter placerade utanför studieområdet. Ett sådant upplägg lämpar sig väl för att illustrera konnektivitet på en bredare landskapsnivå (långdistansrörelser) och för arter som inte har några utpräglade kärnhabitat utan istället är i behov av en variation av livsmiljöer, såsom ofta är fallet med de stora däggdjuren.

Försök till valideringar av modelleringsresultaten från Ostlänken gjordes dels genom utlåtanden av viltexperter och dels genom jämförelser med viltolycksdata. Medan viltexperterna gav ett allmänt stöd till modelleringsmetoden och -resultaten, fanns det liten eller ingen relation mellan simulerade viltrörelser och förekomst av viltolyckor.

Fortsatta steg för metodutveckling och validitetstestning föreslås.

1 Introduction

Background

In most large Swedish road and railway projects, occurrence and movements of large wildlife is assessed to inform the planning of mitigation measures such as wildlife passages and fencing. As large mammal abundance is difficult and time consuming to measure in field, the assessment for infrastructure planning has traditionally made use of experiences and opinions of local hunters and wildlife biologists, assuming that they have a perception of animal concentrations and movement corridors on their hunting grounds. While this assumption is likely correct in most cases, the approach could be criticized for being subjective, and putting more emphasis on areas well known by the informants and on recent observations rather than the long-term situation reflecting the life span of a road or a railway (which is typically 60-100 years).

Figure 1. Roe deer and moose are among the most common large mammals in Sweden, and important target species when planning measures to mitigate the impact of roads and railways on wildlife.

In order to find a more objective basis for planning of wildlife measures, during the past few years the Swedish Transport Administration (STA) has supported the development of methods applying GIS modelling of connectivity for wildlife in landscapes with habitats of different preference to wildlife. In particular, software modelling using circuit theory (programme Circuitscape; McRae et al. 2008) has been explored, as this is considered to produce the most informative and easy-to-understand illustrations of wildlife movements (Seiler et al. 2015a) and is well suited for linear infrastructure planning (see below).

Under the general direction of STA, and conducted by contracted technical consultants, the GIS software Circuitscape has been tested with different types of indata, model settings and output presentation in a number of practical infrastructure planning projects (e.g. Olsson 2014, Sjölund & Olsson 2015, Seiler et al. 2015a, Askling et al. 2015, Helldin et al. 2016, Sweco 2016). The aims of the tests have been to investigate how the model is best applied in Swedish infrastructure planning, and how the model output can be comprehensively presented and correctly interpreted.

The application of circuit theory modelling has been further developed in the ongoing planning for two high speed railways in south-central Sweden, Ostlänken (OL) and Götalandsbanan (GLB). These are large infrastructures, some 150 and 190 km respectively (see Fig. 2), and fenced for wildlife, therefore essentially cutting the country from east to west. Accordingly, planning for wildlife connectivity requires a focus on the larger scale, i.e. taking regional wildlife movements into account, such as dispersal or seasonal movements. The aim of the modelling was to identify large-scale patterns of wildlife movements, significant barriers created by the planned railways, and the need for wildlife passages to mitigate any barrier effects.

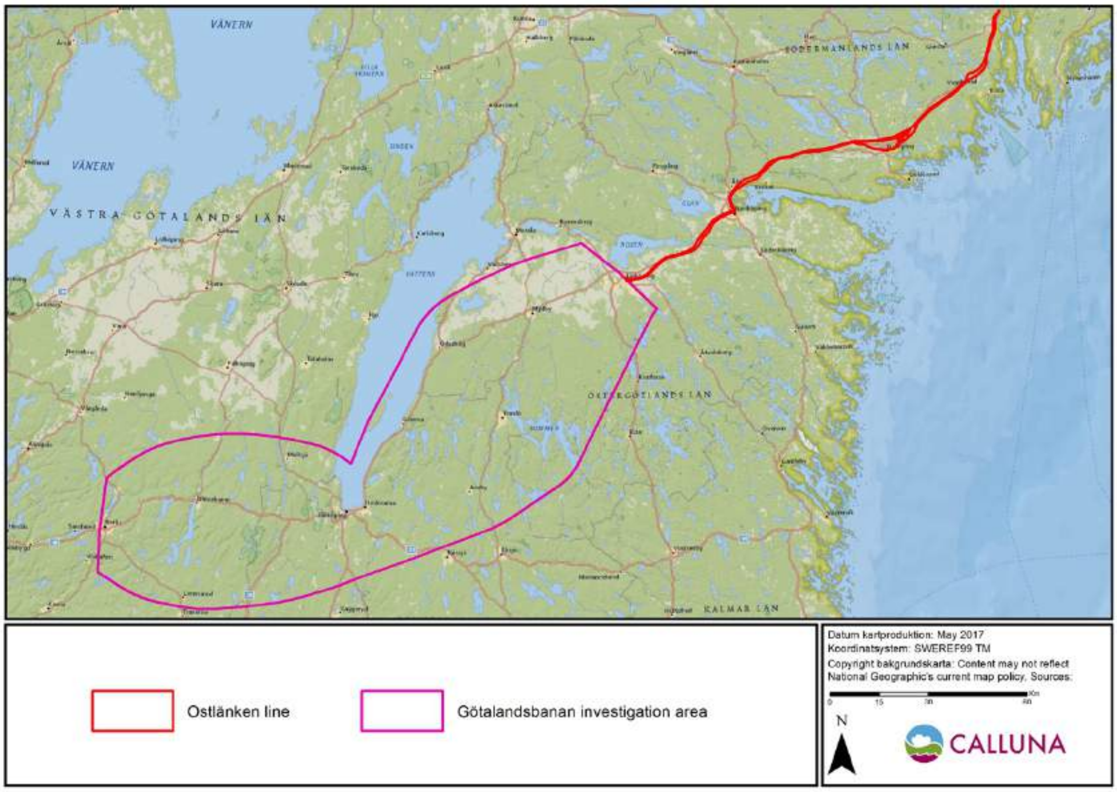


Figure 2. Ostlänken line (OL) and Götalandsbanan investigation area (GLB) in south-central Sweden.

Aim of the report

In this report, the wildlife (ungulate) movement simulation as applied in OL and GLB projects is described in detail, including sources for input data and habitat resistance values. Tentative validations of the model output through expert opinion and with data on wildlife road casualties are described. The complete results of the simulations are presented in separate reports (Trafikverket 2017, Helldin 2017).

2 Method

Patch-free circuit theory modelling

Wildlife movements through the landscape were simulated based on the animals´ preferences for different habitats, in combination with the barrier effects caused by roads and railways, and the opportunities for the animals to pass the infrastructure via bridges, tunnels, culverts etc. Simulations were conducted with the Circuitscape model (McRae et al. 2008) in ArcMap 10.3 (ESRI) GIS software environment.

The use of this software builds on the assumption that the movements of individual animals resemble the movement of charge through an electrical circuit, and that animals experience different resistance to movement in different habitats similar to electrical current passing through resistors. The landscape is divided in cells (raster pixels) as the minimum unit. Each cell is given a resistance value depending on its habitat (including egde zones, built up areas, linear infrastructure etc.), reflecting the animal´s resistance to enter that cell from a neighboring cell. The software calculates the total resistance of each possible route between two nodes in the landscape, and cell values obtained for current flow reflect the probability of an animal passing through that cell on its way from one node to another.

As the software operates on a cell-by-cell basis, it is particularly suited for simulating dispersal movements, where animals are not aquainted to the landscape they are passing through but has to judge where to go next based on the nearest surroundings (Ament et al. 2014). Circuit theory models are highly useful for understanding connectivity on a wider landscape level, and to point out concentrations of movements and potential bottlenecks. This makes them particularly suited for use in linear infrastructure planning, both in the early planning phases when the infrastructure corridor is selected, and in later phases during the siting of wildlife passages and fencing. However, the results must be interpreted with care, since the animal movements through large areas of suitable habitat will be diffuse, and the flow passing through any particular cell in such areas will be lower. The highest values typically occur where animal movements are for any reason pinched, while the ideal situation for wildlife is likely where they are free to select their route and where values thus become intermediate.

The nodes, where animals start or end their routes, can be given different shapes (e.g., point, line or patch), and model outputs from different pairs of nodes can be multiplied to simulate omnidirectional movements (Pelletier et al. 2014, Seiler et al. 2015a), depending on the requirements in a particular project. Core habitat patches can be used as nodes, but when such patches are difficult to define, patch-free connectivity surfaces can be obtained by placing dummy nodes outside of the study landscape. Patch-free models are suitable for answering questions about flow between one broad region and another, for species with diverse needs for habitat quality and quantity (Pelletier et al. 2014) as is often the case for large wildlife.

Application in OL and GLB projects

Species specific resistance values

Simulations were done for moose (*Alces alces*) and roe deer (*Capreolus capreolus*). These are target species for wildlife measures in most road and railway projects, as they are common and distributed over most of Sweden, and in the focus of public interest. The two species are complementary in that they differ in habitat preferences, movement range and demands for passage dimensions. While neither of the species express strong habitat preferences, moose are generally more connected to forest habitats, cover larger ranges, and require larger wildlife passages. Roe deer also use forest habitats but are mainly found in agricultural areas, and the two species combined can be used to point out the importance of securing wildlife connectivity in both open and forested landscapes. The moose functions as an umbrella species when it comes to passage dimensions – what works for the moose should work for all other large wildlife. Roe deer, on the other hand, can use smaller (narrower, lower) passages and can therefore find additional ways past a road or a railway, but due to their smaller movement ranges will have more difficulties finding any larger passages.

Species profiles were created for moose and roe deer respectively, consisting of resistance values for all habitat types, including edge zones, ”non-habitat” such as open water and built up areas, road and railway barriers, and passages through road and railway bridges (see Table 1). In the lack of direct knowledge about how these species choose travel routes, it was assumed that their habitat preferences reflect this choice. General wildlife habitat preferences were determined based on literature and wildlife expert knowledge (see Table 2 for sources). For moose, resistance values were adapted to conform to the values used in previous simulations presented by Seiler et al. (2015a), to enable comparison of outputs.

Table 1. Habitat resistance values used in ungulate movement simulations (modelling using program Circuitscape) for the planning of OL and GLB. Only moose and roe deer were used in final simulations. See text for further details.

Habitat		**Range 1-3**				**Range 1-100**			
In Swedish	*English translation (approximate)*	**Moose**	**Red deer**	**Roe deer**	**Fallow deer**	**Moose**	**Red deer**	**Roe deer**	**Fallow deer**
Marktäcke	**Land cover**								
Barrblandskog	Mixed coniferous forest	1	1	2	3	2	1	50	100
Barrsumpskog	Coniferous forest marsh	1	1	2	3	2	1	50	100
Granskog	Spruce forest	1	1	3	3	2	1	100	100
Tallskog	Pine forest	1	1	2	3	2	1	50	100
Lövblandad barrskog	Coniferous forest, deciduous mixed	1	1	2	2	2	1	50	50
Triviallövskog	Northern deciduous forest	1	1	2	2	1	1	50	50
Triviallövskog med ädellövinslag	Northern deciduous forest, southern mixed	1	1	2	2	1	1	50	50
Lövsumpskog	Deciduous forest marsh	1	1	2	2	1	1	50	50
Ädellövskog	Southern deciduous forest	1	1	2	2	1	1	50	50
Ungskog inklusive hyggen	Forest plantations and clearcuts	1	1	1	2	1	1	1	50
Sumpskogsimpediment	Forest marsh impediment	1	1	2	2	4	1	50	50
Övriga skogsimpediment	Other forest impediment	1	1	3	3	3	1	100	100
Icke-urban park	Non-urban park	2	1	1	2	50	1	1	50
Betesmark	Pasture	2	2	2	1	50	50	50	1
Äng	Meadow	2	2	2	1	50	50	50	1
Hävdad våtmark	Managed wetland	2	2	2	1	50	50	50	1
Limnogen eller saltpåverkad våtmark	Limnogene or marine wetland	1	1	2	2	4	1	50	50
Våtmark	Other wetland	1	1	2	2	4	1	50	50
Odlad mark	Cropland	2	2	1	1	50	50	1	1
Sjöar och vattendrag, igenväxande yta	Lakes and streams, overgrowing surface	1	1	2	2	1	1	50	50
Sjöar och vattendrag, övriga	Lakes and streams	2	2	3	3	50	50	100	100
Hav	Sea	2	2	3	3	50	50	100	100
Tätorter	Urban areas	3	3	3	3	100	100	100	100
Enstaka byggnader	Single buildings	3	3	3	3	100	100	100	100
Friluftsanläggningar	Outdoor facilities	3	3	3	3	100	100	100	100
Övrig exploaterad mark	Other exploited land	3	3	3	3	100	100	100	100
Substratmark	Bare ground	3	3	3	3	100	100	100	100
Övrig öppen mark	Other open land	3	3	3	3	100	100	100	100
Kantzoner	**Edge zones**								
Skog/Odlad mark	Forest/Cropland	1	1	1	1	2	1	1	1
Skog/Betesmark & Äng	Forest/Pasture & Meadow	1	1	1	1	2	1	1	1
Skog/Sjöar och vattendrag	Forest/Lakes and Streams	1	1	1	1	2	1	1	1
Sjöar och vattendrag/Odlad mark	Lakes and streams/Cropland	1	1	1	1	2	1	1	1
Sjöar och vattendrag/ Betesmark & Äng	Lakes and streams/Pasture & Meadow	1	1	1	1	2	1	1	1
Hav/Skog	Sea/Forest	1	1	1	1	2	1	1	1
Hav/Odlad mark	Sea/Cropland	1	1	1	1	2	1	1	1
Hav/Betesmark & Äng	Sea/Pasture & Meadow	1	1	1	1	2	1	1	1
Infrastruktur	**Infrastructure**								
Motorväg E4	Motorway E4	∞	∞	∞	∞	∞	∞	∞	∞
Höghastighetsjärnväg	High-speed railway	∞	∞	∞	∞	∞	∞	∞	∞
Övrig järnväg	Other railway	3	3	3	3	100	100	100	100
Väg_klass_1, övriga	Other primary road	3	3	3	3	100	100	100	100
Väg_klass_2	Secondary road	3	3	3	3	100	100	100	100
Väg_klass_3-4	Minor road	2	2	2	2	50	50	50	50
Bro vilteffektivitet =1	Bridge wildlife effectivity =1	2	2	2	2	25	25	25	25
Bro vilteffektivitet <1	Bridge wildlife effectivity <1	3	3	3	3	100	100	100	100

Table 2. Sources for habitat preferences of ungulates used to produce the habitat resistance values in Table 1.

Species	Literature references	Personal communication
Moose	Seiler et al. (2015a)	-
Red deer	Jarnemo (2014), Allen et al. (2014)	A. Jarnemo, Halmstad University
Roe deer	Winsa (2008)	P. Kjellander, SLU
Fallow deer	Winsa (2008), Kjellander et al. (2012)	P. Kjellander, SLU

In an early stage of the work, also red deer (*Cervus elaphus*) and fallow deer (*Dama dama*) were considered potential target species, and hence species profiles were produced for these in the same way as for moose and roe deer (see Table 1). The red deer profile however ended up resembling the moose profile, and a test run revealed small differences in movement patterns between moose and red deer (Fig. 3). Likewise the fallow deer profile and movement patterns resembled those of the roe deer (Fig. 4). Accordingly, further simulations for red and fallow deer were excluded for the sake of simplicity, and these species were assumed to be covered by the simulations for moose and roe deer.

Range of resistance values

In the case of OL, resistance values were standardized to integers 1-3, except for fenced portions of the largest infrastructures (high-speed railway and motorway) that was considered absolute barriers (infinite resistance). On the scale 1-3, 1 represented land cover with preferred habitats where animals can move freely, 3 represented the least preferred land cover where animals accordingly were three times less likely to pass, and 2 represented an intermediate class of habitats that are frequently used but not preferred. We assumed this three-fold range in resistance to reflect the significant but rather weak habitat preferences expressed by wild Swedish ungulates (Olovsson 2007, Winsa 2008, Jarnemo 2014).

In the case of GLB and in an early stage of the OL work, resistance values ranging 1-100 were used, as resistances in this order of magnitude have been used in several previous simulations of wildlife movements in Sweden (Sjölund & Olsson 2015, Seiler et al. 2015a) and elsewhere (Beier et al. 2008, Dickson et al. 2013, Pellertier et al. 2014, Chambers 2015). A wider range in resistance value gives more contrasts in model outputs and therefore more distinct movement corridors (example given in Fig. 5) which can be desirable in certain cases. We however considered this wider span between lowest and highest resistance to have less support in empirical data of the species at hand, and in the case of OL the 1-100 simulations were finally excluded.

Land cover data

Data on habitat distribution were obtained from official Swedish land cover data (KNAS and SMD; Metria Geoanalys 2009, Naturvårdsverket 2014) except for built up areas where data from Open Street Map were considered more functional. When the definitions of habitats in empirical wildlife studies did not match KNAS/SMD land cover habitats, approximations were made with help of the wildlife experts. Edge zones between habitats were created of a 50 m buffer on each side of the habitat border. Data on transport infrastructure including traffic flow (vehicles/day) and fencing were obtained from STA´s national data bases on roads (NVDB) and railways (”Järnvägsnätet” digital map). Barrier effects of transport infrastructures were derived from standardized effects sizes previously used in road and railway planning (Helldin et al. 2010, Seiler et al. 2015b), and effectiveness of bridges as wildlife passages were derived from STA´s national data base (building on assessments described in Seiler et al. 2015b and Enetjärn Natur 2015).

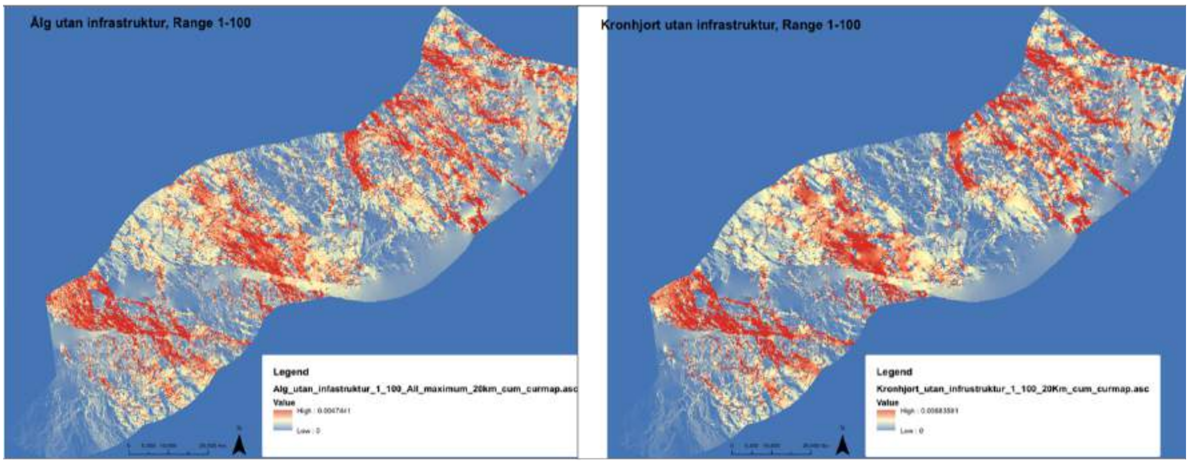


Figure 3. Simulated movement patterns of moose (left) and red deer (right) along OL, based on resistance values presented in Table 1. Due to the resemblance in habitat preferences of the two species, and accordingly in the simulated movement patterns, red deer were excluded from further simulation and assumed to be covered by the results for moose.

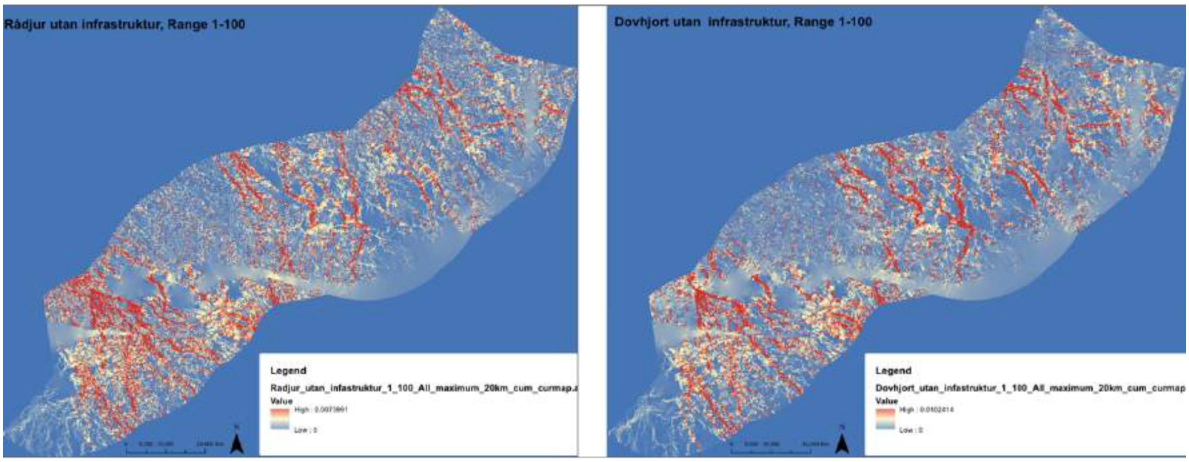


Figure 4. Simulated movement patterns of roe deer (left) and fallow deer (right) along OL, based on resistance values presented in Table 1. Due to the resemblance in habitat preferences of the two species, and accordingly in the simulated movement patterns, fallow deer were excluded from further simulation and assumed to be covered by the results for roe deer.

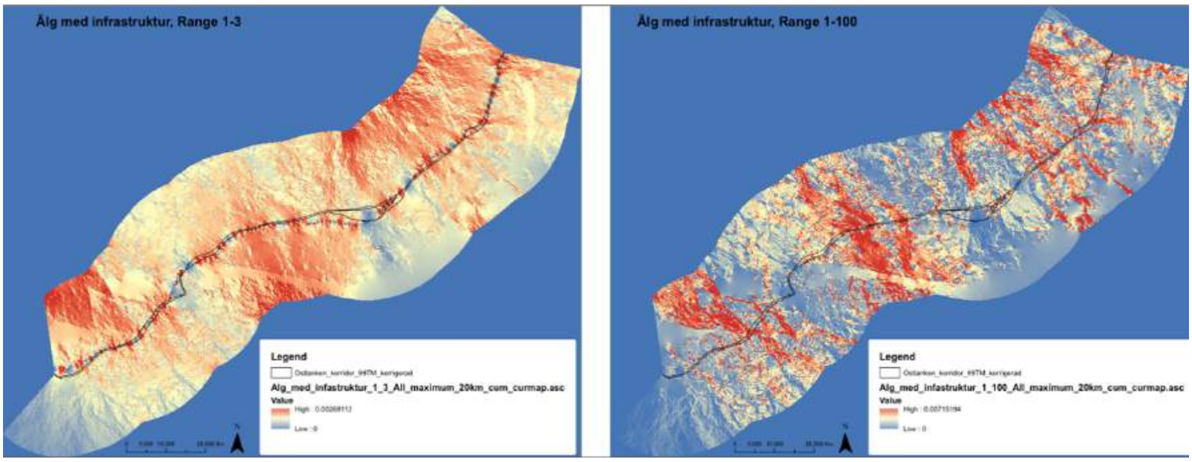


Figure 5. Simulated movement pattern of moose along OL, as an example of the difference between resistance values ranging 1-3 (left) and 1-100 (right).

Resistance layers

Based on the above, resistance layers with raster pixels 20x20 m were produced for moose and roe deer, respectively, for the OL and GLB study areas (Fig. 6). In the case of OL, layers were separated between the four sub-sections of the railway line (OLP1-4), but were possible 10 km of the adjacent sub-section was included in the layer to minimize edge effects.

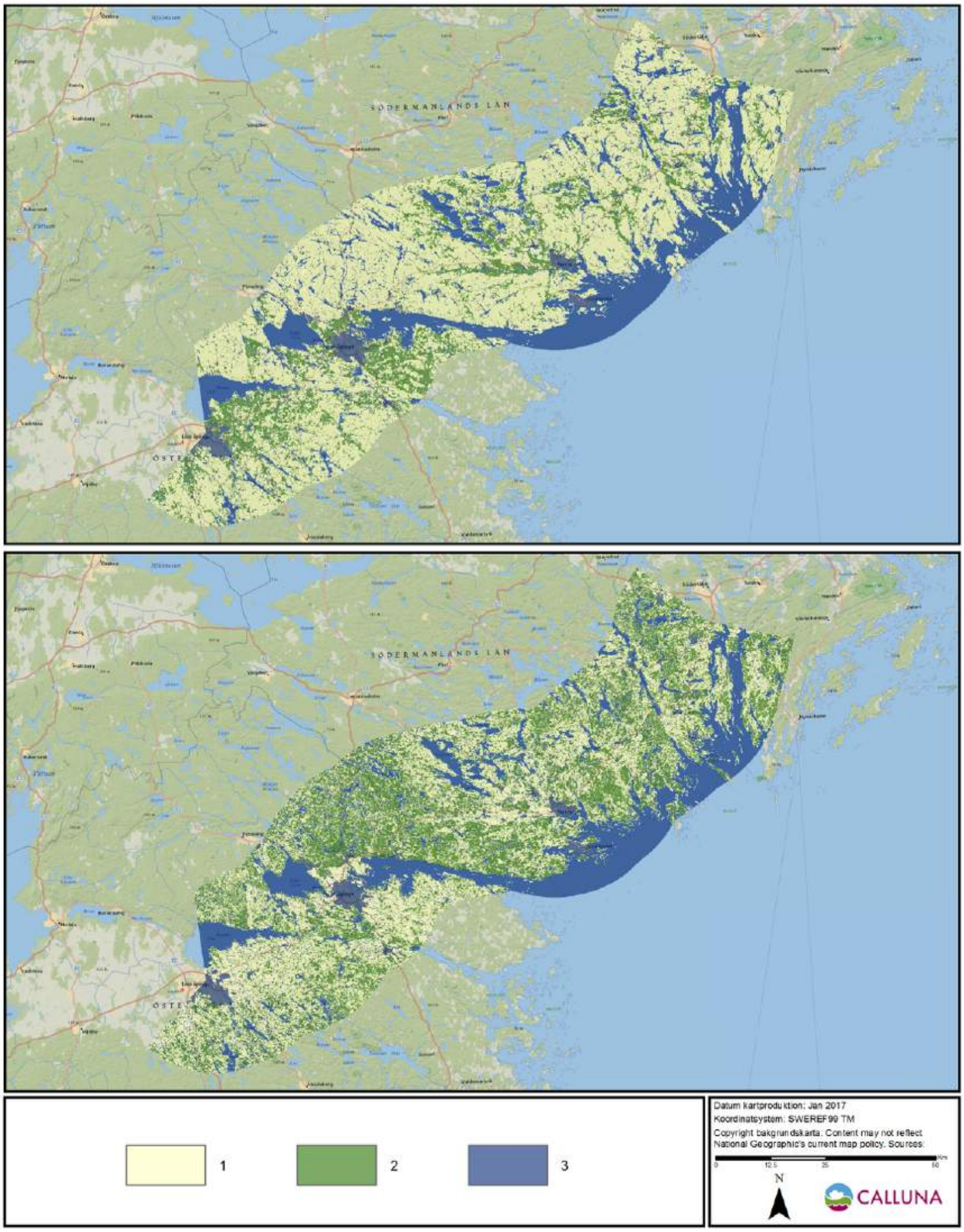


Figure 6. Resistance layers for moose (above) and roe deer (below) used in simulations of movement patterns along OL.

Placement of nodes – directions of movements

In the case of OL, the assessment was designed to illustrate wildlife movements on the larger geographic scale (between regions) and in particular those movements that could be compromised by the new railway, i.e. movements perpendicular to the planned railway line. Therefore, modelling was conducted using two parallel linear nodes placed on each side of the railway corridor, on a distance of 20 km from the corridor (see Fig. 7). The outer 10 km of the modelled area was then cropped to minimize edge effects; still the model output could be expected to be least biassed along the actual railway corridor (i.e. the central line of the modelled area).

For GLB, the assessment was also designed to illustrate large-scale movements, but with less emphasis on perpendicular movements, since the exact corridor for the railway line was not known. Hence, eleven point nodes were arbitrarily distributed around the area under study, on a distance of 10 km to minimize edge effects (see Fig. 8). Model runs were made for all combinations of node pairs and the results were summarized.

In an earlier stage of the work, test runs were made with nodes placed four-sided around the respective area of investigation, hence modelling the combined animal movements parallel and perpendicular to the lines. We considered the outputs from these tests more difficult to interpret and less relevant to identify the animal movements at risk from the coming railways, and accordingly this node setup was not further applied. However, we acknowledge that node configuration needs further development and deeper analysis (see below about recommendations for future method development).

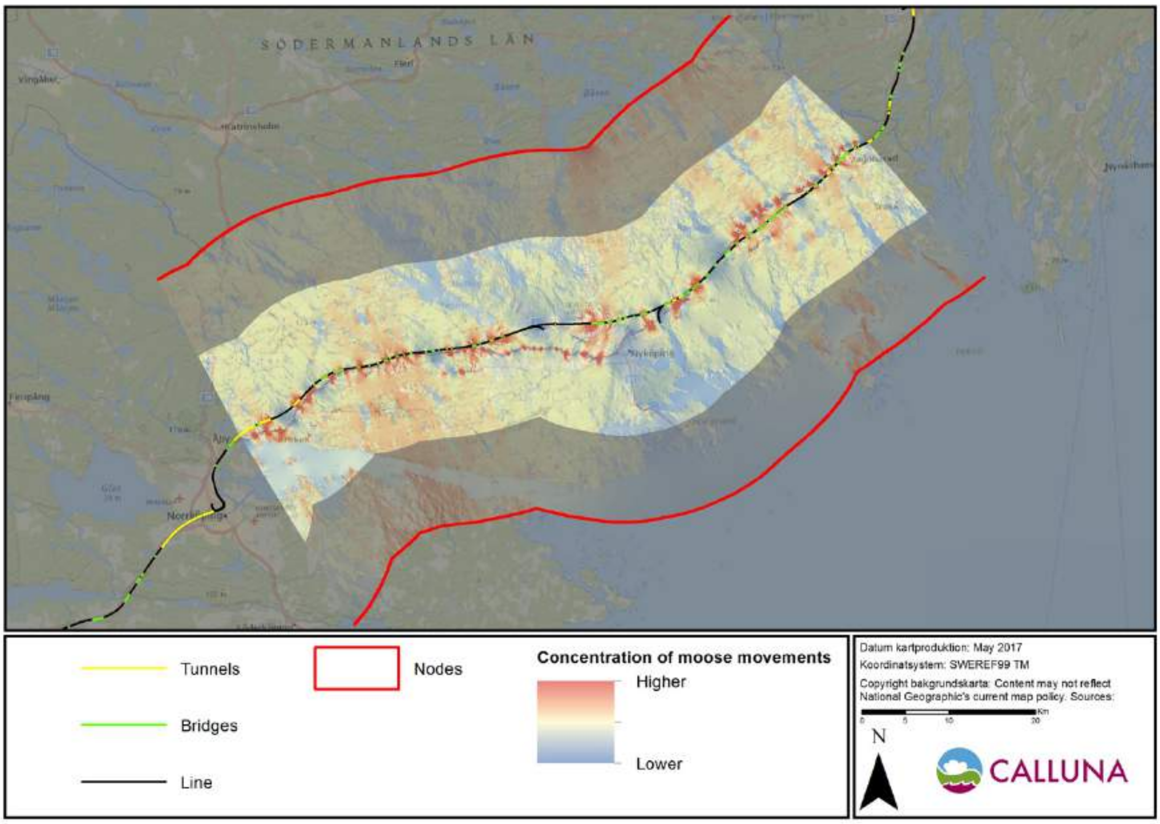


Figure 7. Placement of nodes in the case of OL (here illustrated by part of the line); parallel to the planned line.

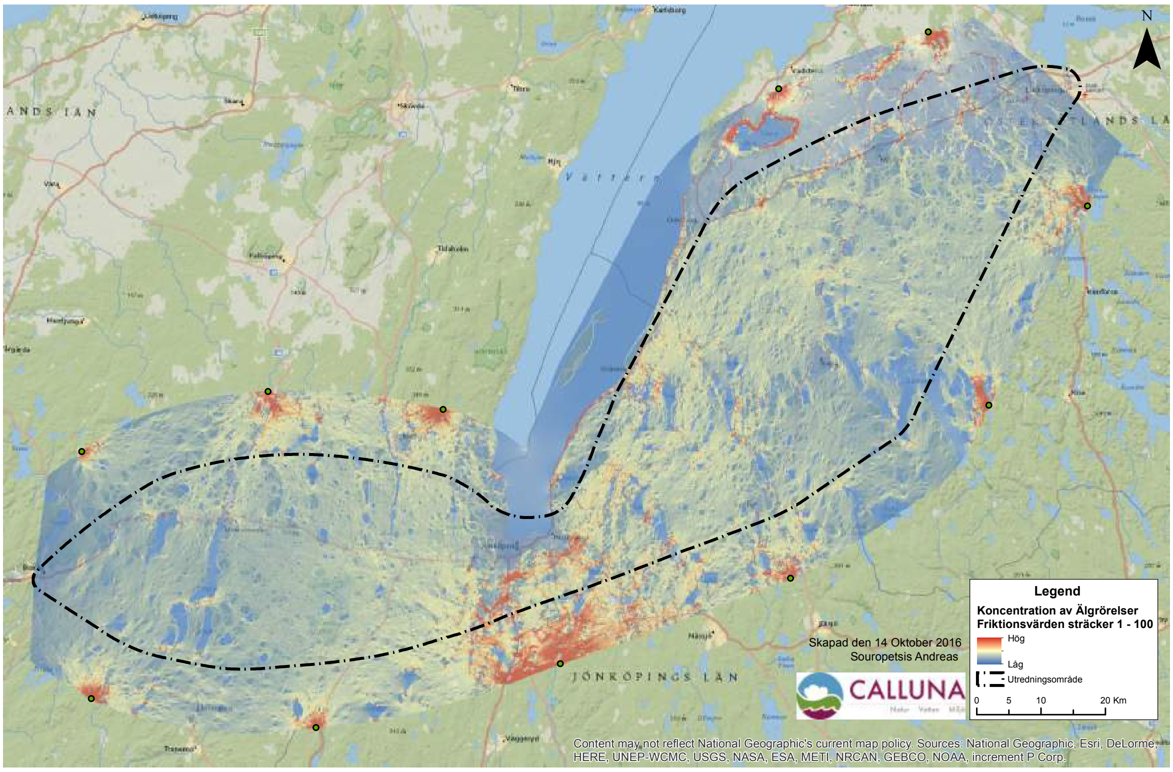


Figure 8. Placement of nodes in the case of GLB; eleven point nodes distributed around the study area.

Model runs

Movement simulations were conducted for each resistance layer. For OL, simulations were made in different scenarios for comparison:

1) Without infrastructure barriers, i.e. where only the habitat distribution structures animal movements.

2) With existing infrastructure, i.e. the present situation.

3) With existing infrastructure and the planned OL with its bridges and tunnels (this scenario could not be simulated for OLP1 as the line was not known).

Examples of simulation outputs are given in Fig. 7-8 and on front cover. All outputs are presented in Helldin (2017) for OL and Trafikverket (2017) for GLB.

3 Validation of model outputs

Some tentative efforts were done to validate the outputs from the circuitscape modelling with expert opinion and with data on wildlife road casualties. Modelling results from OL were used in the validations, hence the modelling represented only long-distance movements perpendicular to the planned railway.

Validation by expert opinion

Regional wildlife experts and stakeholders with presumably good knowledge of wildlife density and movements on the regional scale were invited to ”groundtruth” the model outputs. These experts and stakeholders represented hunters organisations, land owners organisations, wildlife managers and county administrative officers. The method, indata, outputs and tentative conclusions were presented and discussed in meetings. Meeting notes were taken (in Swedish; available on request).

For what this type of qualitative or ”soft” validation may be worth, wildlife experts gave an overall support to the modelling approach, to the method and indata, in particular the smaller range of resistance values (1-3), as this was considered to better represent how animals actually use the landscape. Though comparisons were only done on a general or regional-wide level, and with no systematic analysis of all details, there appeared to be a generally good agreement between the model outputs and the perceived real wildlife movement patterns. The model seem to have well illustrated larger tracts of suitable habitat where wildlife meets few movement obstacles, and major pinch points for wildlife movements created by landscape features (lakes, forests and fields), urban areas and existing infrastructure.

Validation by wildlife casualities

Model outputs were also validated with data on wildlife casualties on roads in the region, with the assumption that more wildlife accidents should occur on road sections crossing areas with simulated dense wildlife movements. All police reported wildlife–vehicle accidents between 1 Jan 2012 and 30 June 2016 (4.5 yrs) from an area within 10 km from the OL corridor were used in the analyses. Accident data were retrieved from the official wildlife accident data base (Viltolycksdatabasen; www.viltolycka.se). Only state-owned roads were included in the analyses, and fenced road sections were excluded. Data on roads with traffic density were retrieved from the national road data base (Nationella Vägdatabasen; www.nvdb.se).

We compared simulated animal movement density (log(*current flow*)) and traffic density (log(*vehicles/24h*)) between accident sites and randomly selected points using logistic regression run in programme R. In each analysis, random points were 10x the number of accidents but were given only 10% of the weight (a procedure recommended for similar data by Barber-Massin et al. 2012). Tests were run with and without log(*current flow*) as explanatory variable, to get a measure of the relative importance of simulation results in determining accident sites. Separate analyses were conducted for moose, roe deer and fallow deer (in the latter case using roe deer movements density, as this was assumed to represent also fallow deer movements; see above). The number of red deer accidents was considered too few to allow analysis.

The tests generally pointed at a weak or no relation between simulated animal movements and wildlife accidents (Table 3). Only for fallow deer the current flow contributed significantly in explaining locations of accidents, but even in this case explained <1% of the variation. In all tests however, traffic density was a highly significant explanation to the location of accidents. Accordingly, the validation using wildlife accidents gave weak support to the model output and hence to the modelling approach.

Table 3. Test statistics for logistic regressions to validate model output (simulated animal movements) with wildlife road casualties, taking also traffic density into consideration. Stars denote level of significance, *n* is number of accidents for each species. See text for further details.

Moose (*n*=156)					
Coefficient	Estimate	Std error	*z*-value	*P*-value	% explained
Intercept	-0.31	0.15	-2.12	0.03*	
Log(*current flow*)	0.04	0.13	0.29	0.77	-
Log(*vehicles/24h*)	1.08	0.16	6.81	<0.001***	14.63
Roe deer (*n*=1081)					
Coefficient	Estimate	Std error	*z*-value	*P*-value	% explained
Intercept	-0.29	0.05	-5.34	<0.001***	
Log(*current flow*)	0.06	0.05	1.14	0.25	-
Log(*vehicles/24h*)	1.07	0.06	17.95	<0.001***	14.46
Fallow deer (*n*=279)					
Coefficient	Estimate	Std error	*z*-value	*P*-value	% explained
Intercept	-0.15	0.10	-1.54	0.12	
Log(*current flow*)	0.21	0.10	2.16	0.03*	0.6
Log(*vehicles/24h*)	0.88	0.11	7.96	<0.001***	10.1

4 Future method development

Modelling of wildlife movements is increasingly applied in landscape connectivity analysis and land use planning (Spear et al. 2010, McRae et al. 2008, 2012, Zeller et al. 2012, Koen et al. 2014), though the importance of further method development and validation is required (Sawyer et al. 2011, Zeller et al. 2012). There is a lack of general consensus on the appropriate choice of environmental data or analytical approaches (Spear et al. 2010). Accordingly, the modelling method, including details of settings and input data, needs to be carefully selected in each planning project and for each question addressed.

Circuit theory modelling of wildlife movements with the programme Circuitscape has recently been used in a number of Swedish infrastructure construction projects (e.g. Olsson 2014, Sjölund & Olsson 2015, Askling et al. 2015, Helldin et al. 2016, Sweco 2016), and has also been assessed more scientifically (Nicholson et al. 2014, Seiler et al. 2015a). The general method now seems to become a national standard for wildlife connectivity modelling in transport infrastructure planning. The Swedish Transport Administration (STA), with help of a number of contracted consultants, has supported the development of an application of the Circuitscape programme that is comprehensive and ecologically well founded, yet manageable and relevant in relation to the practical issues of a construction project.

The present report describes one current step in this method development. The method we used however still has its limitations and likely its flaws.

It is obvious that the modelling output and therefore potentially the conclusions relies heavily on the habitat resistance values. The values used in the OL and GLB projects were selected to the best of our knowledge, but they are yet uncertain, as they are simplified, in part extrapolated outside available knowledge, and relies on a number of assumptions. It is imperative for the future development of this planning method that available empirical positioning data on wildlife are analysed for movement rates in all relevant habitats, to produce a stronger foundation for resistance values. It is of particular importance to gain knowledge of the effect size of the habitat choice, i.e. *how much* more probable is it that an animal enters a certain habitat compared to other habitats, as this should govern the selection of range in resistance values. Some habitats of particular importance need extra focus, either because they are common and therefore have large impact on the modelling output, or because the use of these habitats are particularly little known. Examples of habitats needing extra focus are urban and exploited areas, lakes and streams, and cropland. Also movement rates in edge zones and over linear infrastructures need to be better known. Studies should investigate any differences in movement rates between resident and dispersing animals, between ages and sexes, between seasons, and between night and day. If possible, also changes in movement patterns over the life-span of a major road or railroad should be investigated.

One species that may need an extra effort is the wild boar (*Sus scrofa*). This species was not included in the present study, as we judged the available knowledge of its habitat preferences in Sweden (Lemel et al. 2003, Thurfjell et al. 2008, Thurfjell 2011) impossible to translate into resistance values for land cover types. Wild boar are however of increasing importance for road and railway planning in Sweden, as the population is steadily increasing and larger animals pose a serious threat to traffic safety, and should accordingly be included among the modelled species.

Another aspect needing particular focus in future method development is the configuration of nodes. Depending of the requirements of the planning, different size, shape and placement of nodes can be recommended. These requirements may change over the course of an infrastructure planning project, from siting of the transport corridor to the design of wildlife passages and fences.

Most connectivity models assume that animals move between core areas, i.e. high-quality habitat patches where animals reside most of the time. Such core areas logically constitute the nodes. Delineating core areas is however almost always a subjective process, requiring assumptions about species-specific needs for habitat quality and quantity (Ament et al. 2014). As described above, most large mammals utilize a wide range of habitats in an average Swedish landscape, often depending on time of the day and year, sex and age of individuals etc. In such cases, large scale animal movements should best be modelled with dummy nodes placed outside of the area of investigation (Ament et al. 2014, Pelletier et al. 2014). By placing the dummy nodes well outside of the investigated area, any ”proximity effects” (stronger currents near nodes) are minimized. To emphasize movements in certain directions, for example across a given infrastructure corridor, nodes can be placed double-sided (as in the present OL case), but it must then be clarified that the modelling does not cover all animal movement. In cases where the infrastructure corridor is not known, or when mitigation measures are to satisfy the requirements for all individual animals alike, both residents and dispersers, nodes could rather be placed to illustrate omni-directional movements (as described by Pelletier et al. 2014 and Seiler et al. 2015a). We recommend to further explore how different configurations of nodes can best serve different planning phases, while remaining biologically sound.

We consider the results from our validation of the method to be rather weak and have limited inference. The qualitative validation done by wildlife experts was encouraging but gave little input on details of resistance values and animal movements. The validation with data on wildlife casualties is an obvious opportunity, but can be considered dubious because locations of wildlife accident depend heavily on road characteristics such as traffic speed and density and occurrence of fencing (Seiler 2003), and wildlife accident data also have numerous sources of error (Seiler & Jägerbrand 2016). We recommend further validation of modelling output, primarily using any available wildlife positioning data. Wildlife density measures (derived from for example hunters observations) or hunting records provide further opportunities for validation of modelling output, though these data normally have a coarse geographical resolution, and similar to accident data large error margins, and may therefore have limited inference.

Preserving landscape connectivity for wildlife is an important environmental goal in transport infrastructure development (e.g. Trafikverket 2016), and wildlife mitigation measures such as fencing and over- or underpasses often require large economic investments. We believe that decisions for such investments should rely on the best possible foundation. We strongly suggest that the methodology for wildlife movement modelling in Swedish infrastructure planning is further developed, and its validity tested with empirical data.

References

Allen AM, Månsson J, Jarnemo A & Bunnefeld N (2014). The impacts of landscape structure on the winter movements and habitat selection of female red deer. *European Journal of Wildlife Research* 60: 411–421.

Ament R, Callahan R, McClure M, Reuling M & Tabor G (2014). Wildlife Connectivity: Fundamentals for conservation action. Center for Large Landscape Conservation: Bozeman, Montana. [online] Available: <http://largelandscapes.org/media/publications/Wildlife-Connectivity-Fundamentals-for-Conservation-Action.pdf> [2017-04-10]

Askling J, Bovin M, Bergsten A & Collinder P (2015). Ostlänken Stockholms, Södermanlands och Östergötlands län; Rapport Ekologiska samband – underlag för analys av barriäreffekter 2015-11-27. Trafikverket rapport OLP0-04-025-0000-0005. (In Swedish.) Not available online.

Barbet-Massin M, Jiguet F, Albert CH & Thuiller W (2012). Selecting pseudo-absences for species distribution models: how, where and how many? *Methods in Ecology and Evolution* 3: 327–338.

Beier P, Majka DR & Spencer WD (2008). Forks in the Road: Choices in Procedures for Designing Wildland Linkages. *Conservation Biology* 22(4): 836–851.

Chambers SN (2015). Corridors and Elk Migration: A Comparative Analysis of Landscape Connectivity Models and GPS Data in the Greater Yellowstone Ecosystem. PhD Thesis. Tucson, USA: University of Arizona. [online] Available: <http://arizona.openrepository.com/arizona/bitstream/10150/577193/1/azu_etd_14056_sip1_m.pdf> [2017-04-10]

Dickson BG, Roemer GW, McRae BH & Rundall JM (2013). Models of Regional Habitat Quality and Connectivity for Pumas (*Puma concolor*) in the Southwestern United States. *PLoS ONE* 8(12): e81898.

Enetjärn Natur (2015). Manual för verifiering av viltpassager. Unpublished manual. (In Swedish.) Not available online.

Helldin J-O, Seiler A & Olsson M (2010). Vägar och järnvägar – barriärer i landskapet. CBM report no 42. (In Swedish.) [online] Available: <http://media.triekol.se/2013/10/Triekol-CBM-skrift-42.pdf> [2017-04-11]

Helldin J-O, Jarnemo A & Stål Delbanco A (2016). Kronhjort vid E65 Svedala-Börringe – Kompletterande utredning av nya vägdragningsalternativ B och C. Report from Calluna AB. (In Swedish.) Not available online.

Helldin J-O (2017). Ostlänken; Stockholm Södermanland och Östergötlands län, Rapport Viltanalyser - viltrörelser, kritiska sträckor och platser samt åtgärdsbehov; Underlag för planering av viltåtgärder. Report in preparation, from Trafikverket. (In Swedish.)

Jarnemo A (2014). Kronviltprojektet 2005-2013. Slutrapport. Grimsö forskningsstation,Inst för ekologi, SLU. (In Swedish, with English summary.) [online] Available: <http://krets.jagareforbundet.se/linkoping/files/2015/12/Kronviltprojektet_Slutrapport.pdf> [2017-04-10]

Kjellander P, Svartholm I, Bergvall UA & Jarnemo A. (2012). Habitat use, bed-site selection and mortality rate in neonate fallow deer *Dama dama*. Wildlife Biology 18: 280-291.

Koen EL, Bowman J, Sadowski C & Walpole AA (2014). Landscape connectivity for wildlife: development and validation of multispecies linkage maps. *Methods in Ecology and Evolution* 5: 626–633.

Lemel J, Truve J & Söderberg B (2003). Variation in ranging and activity behaviour of European wild boar Sus scrofa in Sweden. *Wildlife Biology* 9: 29-36.

McRae BH, Dickson BG, Keitt TH & Shah VB (2008). Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology* 89(10): 2712-2724.

McRae BH, Hall SA, Beier P & Theobald DM (2012). Where to restore ecological connectivity? Detecting barriers and quantifying restoration benefits. *PLoS ONE* 7: e52604.

Metria Geoanalys (2009). Ny metod för kontinuerlig naturtypskartering av Skyddade områden (KNAS). Report from Metria Geoanalys dated 2009-10-20. (In Swedish.) Not available online.

Naturvårdsverket (2014). Svenska Marktäckedata – Produktbeskrivning. Utgåva 1.1. Report from Naturvårdsverket dated 2014-03-25. (In Swedish.) [online] Available: <http://gpt.vic-metria.nu/data/land/SMD_produktbeskrivning_20140325.pdf> [2017-04-10]

Nicholson K, Seiler A, Olsson M & Lindqvist M (2014). Using Circuit Theory to Rewire Roads for Wildlife. Pg 153 in: Seiler A (Ed.) IENE 2014 International Conference on Ecology and Transportation. Malmö, Sept. 16-19, 2014. IENE & Calluna AB. [online] Available: <http://iene2014.iene.info/wp-content/uploads/IENE_2014_Proceedings_updated_version.pdf> [2017-04-12]

Olovsson A (2007). Habitat selection by moose (Alces alces) in southwestern Sweden. MSc Thesis, Karlstad University. [online] Available: <http://www.diva-portal.se/smash/get/diva2:4800/FULLTEXT01.pdf> [2017-04-11]

Olsson M (2014). Övergripande planering av faunaåtgärder längs E20 i Västra Götalands län. Report from Trafikverket dated 2014-04-24. (In Swedish.) Not available online.

Pelletier D, Clark M, Anderson MG, Rayfield B & Wulder WA (2014). Applying circuit theory for corridor expansion and management at regional scales: Tiling, pinch points, and omnidirectional connectivity. *PLoS ONE* 9(1): e84135.

Sawyer SC, Epps CW & Brashares JS (2011). Placing linkages among fragmented habitats: do least-cost models reflect how animals use landscapes? Journal of Applied Ecology 48: 668–678.

Seiler A (2003). The toll of the automobile: Wildlife and roads in Sweden. PhD Thesis, SLU, Sweden.

Seiler A & Jägerbrand A (2016). Mörkertal i viltolycksstatistiken – resultat från enkätundersökning och analyser av olycksdata. Trafikverket report no 2016:055. (In Swedish.) Not available online.

Seiler A, Sjölund L & Bovin M (2015a). Metod-PM: Test av Circuitscape inför tillämpning inom Ostlänksprojektet. Unpublished report, Grimsö forskningsstation SLU. (In Swedish.) Not available online.

Seiler A, Olsson M & Lindqvist M (2015b). Analys av infrastrukturens permeabilitet för klövdjur. Trafikverket report no 2015:254. (In Swedish.) [online] Available: <https://trafikverket.ineko.se/Files/sv-SE/11690/RelatedFiles/2015_254_analys_av_infrastrukturens_permeabilitet_for_klovdjur.pdf> [2017-04-10]

Sjölund L & Olsson M (2015). Övergripande planering av faunaåtgärder längs E18 och E45 i Västra Götalands län. Report from Trafikverket dated 2015-03-20. (In Swedish.) Not available online.

Spear SF, Balkenhol N, Fortin M-J McRae BH & Scribner K (2010). Use of resistance surfaces for landscape genetic studies: considerations for parameterization and analysis. *Molecular Ecology* 19: 3576–3591.

Sweco (2016). Utvärdering av viltanalyser och resultat av passageåtgärder för OLP2. Report from Sweco Position AB. (In Swedish.) Not available online.

Thurfjell H, Ball JP, Åhlén P-A, Kornacher P, Dettki H & Sjöberg K (2009). Habitat use and spatial patterns of wild boar Sus scrofa (L.): agricultural fields and edges. *European Journal of Wildlife Research* 55(5): 517–523.

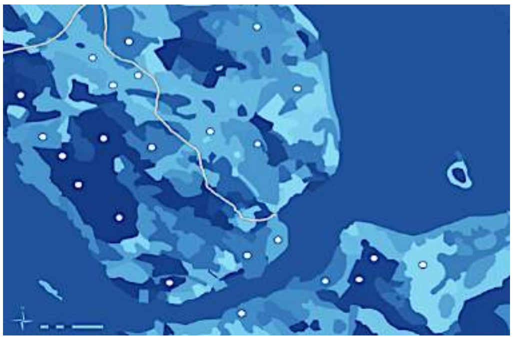
Thurfjell H (2011). Spatial behaviour of Wild boar. PhD Thesis, SLU, Sweden.

Trafikverket (2016). Riktlinje Landskap. Trafikverket document no 2015:0323. (In Swedish.) Not available online.

Trafikverket (2017). Åtgärdsvalsstudie för höghastighetsjärnväg Linköping–Borås, Underlagsrapport Landskapskaraktärsanalys; förhandskopia 2017-02-15. Report in preparation, from Trafikverket. (In Swedish.) [online] Available: <http://www.trafikverket.se/TrvSeFiler/Foretag/Planera_o_utreda/en_ny_generation_jarnvag/linkoping_boras/Underlagsrapport%20Landskapskaraktärsanalys/a_lka_linkoping_boras_fk_20170215_hela_hog.pdf> [2017-04-13]

Winsa M (2008). Habitat selection and niche overlap – a study of fallow deer (*Dama dama*) and roe deer (*Capreolus capreolus*) in south western Sweden. MSc Thesis, Swedish University of Agricultural Sciences.

Zeller KA, McGarigal K & Whiteley AR (2012). Estimating landscape resistance to movement: a review. *Landscape Ecology* 27: 777–797-



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