Final thesis Wildlife management

Road crossing structure suitability for dispersal of the Eurasian lynx (*Lynx lynx*) in the Western Harz region, Germany

(Arndt, 2011)

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Abstract

Fragmentation of the environment affects the dispersal of Eurasian lynx (Lynx lynx). This also occurs in the Harz region, in central Germany, where in 2000 the Luchsprojekt Harz started reintroducing the Eurasian lynx. This constantly growing population causes lynx dispersal including high traffic volume road crossings. The aim of this study was to estimate the most likely road crossing structures the lynx would have used for the road crossings of high traffic roads and by this to gain understanding in the lynx' utilization of crossing structures. The study site was determined by the occurred lynx road crossing and mortality locations and included sections from different highways and motorways. Multiple structure characteristics were measured, which were established based on the lynx species ecology. The data analysis consisted of three parts, (i.)a least cost path (LCP) analysis to estimate the most likely route the lynx could have chosen to cross the road and two statistical analyses: (ii.)comparison of the differences in characteristics of the crossing structures expected to have been used by lynx and crossing structures available but not expected to have been used by lynx and (iii.) analysis of the lynx mortality sites' crossing structures to define the characteristics. The results showed the calculated use of over passages and under passages at the crossing events. These results were contrary to the expectations of a high viaduct use by lynx. The predicted use of structures was higher in the areas where forest leads to the road and continued to the other side of the road, which confirms that cover connections between the crossing and the animal's habitat improve the use of crossing structures. There were differences found in five structure characteristics between the expected and not expected structures to have been used by lynx. Contrary to the expectations, leading structures on both sides of the crossing structures were more present and the mean distance to nearest hiding structure on one side of the structure was shorter at crossing structures which were not predicted to have been used by lynx. Distance to nearest forest was lower at the predicted used and not used road crossing structures. In addition, strong positive relation was found between the leading structures on each side of the structures. Furthermore, no indications on the crossing structure suitability were found from the mortality site data. As a conclusion, it is suggested that the lynx dispersal over high traffic roads in the Western Harz region is expected to utilize road crossing structures to some extent. However, some characteristics, such as the surrounding landscape, are considered to have a higher importance.

Keywords: Dispersal, traffic, Eurasian lynx (Lynx lynx), crossing structure, road crossing, Harz

Introduction

In Germany, high human population density and intensive agricultural land use combined with a dense traffic network lead to a highly fragmented nature environment with negative influence on animal species populations. (EEA-FOEN, 2011; Federal Statistical Office and the statistical Offices of the Länder, 2014) This problem especially affects large carnivore species, such as Eurasian lynx (*Lynx lynx*) (Jedrzejewski et al., 2009; Popa et al., 2012). High traffic volume roads have been recorded as a significant obstacle on the dispersal of lynx (Jedrzejewski et al., 2009; Kusak et al., 2009; Riley et al., 2006). Sub adult individuals seem to have difficulties to overcome these barriers, especially when road fencing is present (Zimmermann et al., 2007). Different European studies show a clear negative correlation between traffic volume (N vehicles/day) and successful animal road crossings (Jedrzejewski et al., 2009; Kusak et al., 2009; Riley et al., 2006). Especially in Germany, the reintroduced lynx populations are vulnerable to the road mortality and research has proven that these populations are restricted to their release patches due to the fragmentation by roads with high traffic volume. (Kramer-Schadt et al., 2004; 2005) This habitat fragmentation by roads can restrict for instance the daily movement or dispersal on the animal. Different studies of young and adult lynx dispersal show a high dispersal range (Samelius et al., 2012; Schmidt, 1998; Zimmermann et al., 2007) even up to 350 km (Jedrzejewski et al., 2009). However, population density and mortality during movement are considered as factors affecting the dispersal distance and direction (Schmidt, 1998). In general lynx mostly try to cross open areas by the shortest path from cover to cover (Russian Academy of Sciences et al., 2003). Contrary to this, they have also been found to travel across small deforested areas as well as agricultural land (Zimmermann et al., 2007). In addition, lynx are also found to travel longer distances close to or within 200 m distance from a road or a trail, depending on the road size, surface and disturbance frequency by vehicles or humans. (Bunnefeld et al., 2006; Kusak et al., 2009; Moen et al., 2010) Under particular circumstances road and trail network can increase connectivity of habitat patches regarding the dispersal movement of lynx (Moen et al., 2010).

This habitat fragmentation also occurs in the Harz region by several crossing motorways and surrounding highways. In 2000 the Luchsprojekt Harz started a reintroduction project of lynx after approximately 200 years of absence of the species in this region. (Luchsprojekt Harz, 2012) A successful reintroduction and a constantly growing population show sub adult and adult dispersal and far distance daily movements during the last years, including dispersal into western direction (Anders, 2011; 2013). Within two subsequent years of monitoring (2011/2012 and 2012/2013), lynx recordings on the western side of highway A7 doubled in number. This attempt of individuals to leave the Harz region and disperse in western direction includes high traffic volume road crossings, which can be regarded as crucial obstacles for their movement. (Anders, 2013) Due to past successful high traffic volume road crossings of GPS collared lynx individuals in the western and southern parts of the Harz region (Luchsprojekt Harz, 2014), the Luchsprojekt Harz wants to gain knowledge on existing artificial road crossing structures that could have been used by lynx. The goal of this research was to give insight in lynx dispersal patterns, more specifically to gain understanding in the lynx' use of crossing structures for high traffic road crossing. For this objective a) the most likely crossing routes the lynx have used for the successful crossings and b) the characteristics of the crossing structures at occurred successful lynx crossing sites as well as c) at lynx road mortality sites over high traffic roads on the borders of the Harz area were studied.

In this article the terms "crossing" and "road crossing" are used for the event of lynx crossing a road from one side to another, when "a crossing structure" is used to describe the physical structures, such as bridges and tunnels.

Methods

Study area

This study concentrated on the western border of the Harz region located in central Germany (N 51.7214°, E 10.5242°) (Figure 1). Due to the large differences in elevation, the Harz region comprises different vegetation stages, from sub-mountainous to subalpine level, including plant communities like red beech forests, mixed beech and spruce woodlands and mountain spruce dominated areas (Büttner & Kison, 2009). This high diversity of biotopes provide suitable habitat for a large number of species including large carnivores such as the lynx (Luchsprojekt Harz, 2012).

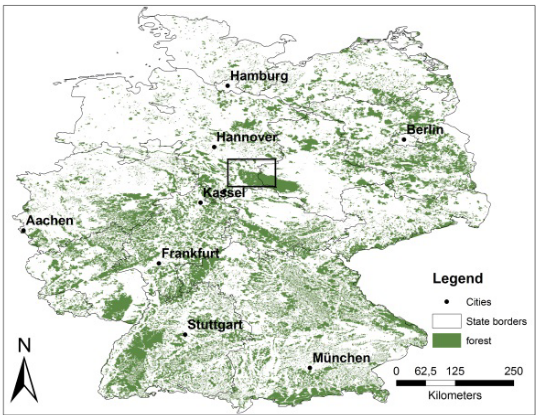

Figure 1: The square indicates the study area in the Western Harz region, in central Germany (MapCruzin, 2014).

Study species

In Europe, the Eurasian lynx (*Lynx lynx*) occupies Scandinavia, Eastern Europe, Western Siberia, and two very small reintroduced populations in Germany. (Breitenmoser & Breitenmoser-Würsten, 2008; Kora, 2004) Lynx are territorial felids, preferring mixed and deciduous forested areas, with females and males having each their own territories (Alderton, 1993; Breitenmoser & Breitenmoser-Würsten et al., 2008; Nowak, 2005; Sunquist & Sunquist, 2002). Four important factors influencing the size of the lynx territory are: (i) the amount of individuals within the population, (ii) prey density, (iii) extension of suitable habitat and (iiii) ground structure (Breitenmoser & Breitenmoser-Würsten et al., 2008). These factors affect the three main behaviour requirements of hunting, resting and reproduction (Herfindal et al., 2005; Jedrzejewski et al., 2009; Podgorski et al., 2008). In Western and Central Europe the size of the territories, when female and male data are combined, is between 106 and 264km^2 (Hunter & Barret, 2011). As an exception to these territorial sizes, female lynx are known to decrease their home range size while raising young. (Breitenmoser & Breitenmoser-Würsten et al., 2008; Nowak, 2005; Schmidt et al., 1997) The young leave their mother at the age of nine to eleven months (Luchsprojekt Harz, 2012; Nowak, 2005; Schmidt, 1998), after which the young adults need to find an unoccupied area (Sunquist & Sunquist, 2002). Worldwide sub adult lynx have been recorded with high mortality (44-60%) during dispersal. However, male lynx of this age category disperse longer distances than the females, which stay closer to their natal range. (Hunter & Barret, 2011) Adult females have a stronger fidelity to their home range, while adult males could shift their territory more often (Schmidt et al., 1997; Sunquist & Sunquist, 2002).

Data sampling

The research site for this study was determined by the lynx successful road crossing and mortality locations (Figure 2). The area covered the motorway B243 between the highway A7 and Bad Lauterberg, which is a four lane motorway with a total width of 20m with an average daily traffic frequency of 13000 vehicles (Bundesamt für Strassen, 2002; NLStBV, 2012). B242 from the eastern side of Clausthal-Zellerfeld until Seesen, B82 starting from A7 and reaching to Goslar and B248 between Seesen and Salzgitter are all two lane motorways within the northern part of the study site. The four-lane A38 starting from Dreieck Drammetal junction covering sections of different lengths until Sangerhausen, the A7 from Dreieck Drammetal to Hannoversch Munden with six lanes and 31m width (Bundesamt für Strassen, 2002), as well as a short section of the A44 near Zierenberg with four lanes, comprised the southern part of the study site. A short section of the two lane motorway B4 was also part of the study. Additionally, an area with a radius of 150m (Jedrzejewski et al., 2009) on each side of the highways and motorways at every crossing structure was taken into account.

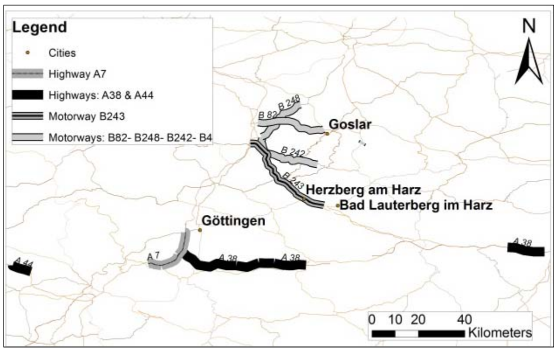

Figure 2: Study sites: roads A7, A38, A44, B4, B82, B242, B243, B248 (MapCruzin, 2014)

Table 1 shows the research population of this study, which consisted of both GPS-collared (five individuals) and un-collared (six individuals) lynx individuals monitored by the Luchsprojekt Harz. Successful road crossings have been recorded by the collared individuals: male lynx M2, M6 and M7, as well as the female F4. Additionally, data on five un-collared lynx' road crossing attempts, which resulted in six (one attempt combined a female with a cub) road mortalities, were used for the analysis.

All the data sampling was performed in ArcGIS 10.1. and Google Earth 7.1.2.2041. The data on all the successful crossing and road mortality locations of the lynx were obtained from the Luchsprojekt's database. The obtained lynx location co-ordinates were combined with the datasets on roads, landscape and places of the area, obtained from MapCruzin (2014), prior to the field survey.

The data sampled included all possible road crossing structures within study sites. The last recorded location of the collared lynx on one side of the road and the first recorded location on the other side of the road were used in the analysis of each successful lynx road crossing. Each of the two GPS locations were buffered using a distance calculated with the mean daily distance of each lynx and the time between the two co-ordinates. The mean daily distance was calculated separately for each individual in Ranges 7 software. The GPS co-ordinates within 15 days prior and 15 days after the road crossing were included for the calculation, in which the mean daily (24h) travelling distance was established. The results resembled distance found by Jedrzejewski et al. (2002). Subsequently, the buffer radius for determining the sampling site was calculated with the following formula:

Buffer radius = [Mean daily distance (m)/ time (24h)] * time between locations (h)

Figure 3 shows an example of the buffers in GIS. From the resulting buffers around the co-ordinates, the road was sampled where at least one of the buffers covered it. Motorways and highways, which were not part of the crossing as well as urban areas, not considered as possible crossing sites for lynx, were regarded as buffer borders. Crossing structures on these roads, or that lay in the opposite direction of the two GPS points (the start and end point of an crossing event) were not included in the analysis.

Where the buffers did not overlay the road, two tangents on the outer borders of the buffers marked the road section for sampling. All the road sections within the buffers were then mapped by sight for all crossing structure co-ordinates in Google Earth before inserting them into ArcGIS.

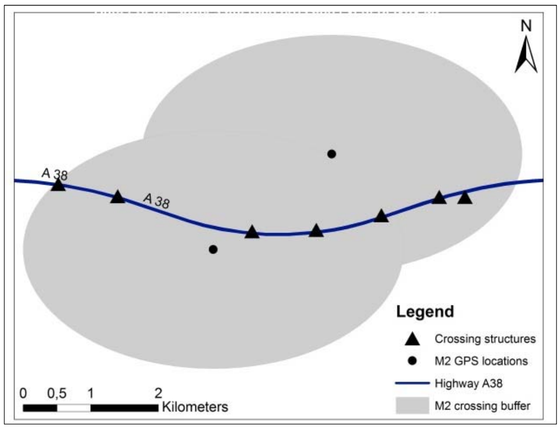

Figure 3: An example of a buffer of the successful road crossing event of lynx M2 including the crossing structures within the sites in ArcGIS.

For the lynx road mortality crossing structure data, the locations were also buffered to identify the crossing sites for sampling. A buffer was created with a 500m radius, decided together with the Luchsprojekt, for each road mortality location, in order to sample only the possible crossing structures accessible to the lynx near the mortality site. Also, the locations of the found lynx were considered as sampling points.

Table 1: Research population displaying the collared (Collar: Y) and road mortality individuals (Collar: N) with information on lynx individual and the location of crossing events/ attempts (Source of data: Anders, 2011; Anders, 2013)

ID	Collar	Sex	Date of trapping / found	Age	Location of trapping/ found	Start tracking	End tracking	Period of crossing events	No. of road crossings	Road ID
M2	Y	M	17.11.08	Juvenile	Münchehof	14.04.09	08.02.10	29.05.09-25.11.09	6	B248/ A38
M6	Y	M	30.04.13	Sub adult	near Bühren/ Göttingen	01.05.14	06.12.13	27.11.13-01.12.13	2	A7
M7	Y	M	30.01.14	Adult	S of Goslar	30.01.14	ongoing	01.02.14-18.03.14	11	B82/B 248
F4	Y	M	05.04./ 08.10.13	Sub adult	close to Altenau / close to Langelsheim	25.04.13	ongoing	28.04.13-19.07.13	9	B248 B242/ B243
1	N	F	03.11.08	-	near Münchehof	-	-	-	-	B243
2	N	n/a	03.11.08	Cub	near Münchehof					B243
3	N	F	07.03.09	-	south of Bad Harzburg	-	-	-	-	B4
4	N	M	15.10.12	-	Between Zierenberg and Breuna	-	-	-	-	A44
5	N	M	08.12.13	-	W of Sangerhausen	-	-	-	-	A38
6	N	n/a	30.04.14	-	N/W of Herzberg	-	-	-	-	B243

Data collection

The data collection was performed during five weeks in April and May 2014 at the Western Harz region. During this time 104 crossing were visited. In some cases, previously unnoticed crossings were discovered and included in the data collection. At the sampling site, both sides of the crossing structure were sampled when reachable. The sides were labelled West or South side (W/S) and East or North side (E/N). Data from a previous study conducted on the crossing structures at the highway A7 by COPRIS (Unpublished) was used in addition. Furthermore, data collection on the distances for the nearest forest and tree patches and traffic intensity for all the sampled crossing structures were conducted in Google Earth and ArcGIS. The data collected, the measuring units, definitions and the methods of the collection on each crossing structure, at all the successful crossing sites and the road mortality sites, are listed and described in Table 2. These specific variables were established with a desktop study and the help of experts on the species ecology. There are a limited number of studies on the road crossing behaviour of the lynx. For that reason, many of the chosen variables were based on a literature on other similar species, such as the European wildcat (*Felis silvestris silvestris*). The equipment used for data collection included a GPS device (Garmin 62s), compass, tape measure and laser range finder (Bushnell TourZ6).

Table 2: Variables in data collection

Variable	Measuring Unit	Definition	Data obtained
Location	GPS co-ordinates	-	Field
Type of road	Definition	Highway, motorway	Field
Number of lanes on the highway/motorway	Number	-	Field
Crossing type	Definition	Viaduct, watertunnel, underpass, overpass	Field
Utilization	Definition	No use, cycle/pedestrian path, farm road, road, railway, water	Field
Length	Meters	-	Field
Height	Meters	-	Field
Width	Meters	-	Field
Type of ground	Definition	Natural ground (soil, small gravel), cobblestone, large gravel (railway), asphalt, concrete, water	Field
Leading structures	Definition & Meters	Shrubs, trees, grass	Field
Road fencing	Present/Absent & Meters	-	Field
Distance to nearest hiding structure	Definition & Meters	Shrubs, trees, grass, crops, no structure	Field
Distance to the nearest forest area >1ha	Meters	-	Google Earth
Distance to the nearest tree patch (<1ha)	Meters	-	Google Earth
Traffic frequency	Vehicles/day & Heavy vehicles/day	-	Map from the Road Construction Office

Data preparation

After the field survey, the data were inserted and prepared further in Microsoft Excel 2010. The data recorded as definitions were divided into suitable categories and coded in number format. These codes were allocated by ranking the impact of the category as a barrier for the dispersal of lynx, lowest value was assigned for the estimated lowest impact. The index of relative openness (permeability), which is a commonly used value by biologists, was calculated for the under passages by the following formula: *(width*height)/length* (Clevenger & Huijser, 2011; Jedrzejewski et al., 2009) and for the over passages by *width/length* (Kramer-Rowold & Rowold, 2001).

In ArcGIS 10.1 the data on the roads and the land use were reclassified in order to give them values according to their barrier effect on the dispersal of lynx. Afterwards, the road layer and the crossing structure data layer were transformed from vector format into raster format (100 m grid size). After the ArcGIS analysis of the most likely route the data was inserted in IBM SPSS Statistics 21 to analyse the characteristics of the crossing structures at occurred successful lynx crossing sites and at lynx road mortality sites.

Data analysis

The data analysis was performed in two parts; first the least cost path (LCP) analysis was conducted in ArcGIS 10.1 to estimate the most likely route the lynx could have chosen to cross the road and subsequently, statistical analysis was performed in IBM SPSS Statistics 21. The statistical analysis was conducted only for the crossing events where a crossing structure was expected to have been used according to the results of the LCP analysis. The differences in characteristics of the crossing structures expected to have been used by lynx and crossing structures available but not expected to have been used by lynx were analysed. In addition, the lynx mortality sites crossing structure data were statistically analysed to define the characteristics.

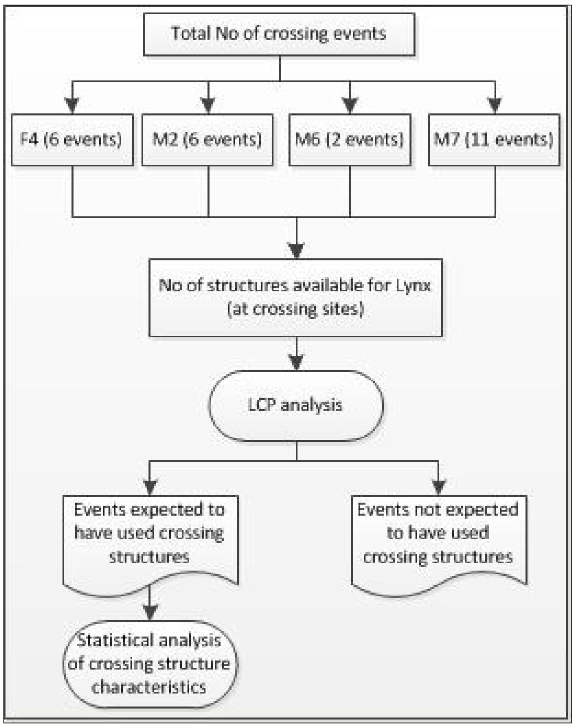

Figure 4: Conceptual model for the data analysis of the successful road crossing events

At the start of the LCP analysis the crossing structure characteristics were valued, for each category within each variable, according to their barrier effect on the lynx dispersal established by a desktop study. Values were assigned with the lowest value to the category with the least barrier effect. The distance variables were not categorized, but included with the existing values. Finally, one end value for every crossing structure was calculated by using assigned multipliers for each variable. The multipliers for different characteristics were assigned according to their scale of influence on the crossing and in order to differentiate the importance of each characteristic. Characteristics with larger influence, such as distance to nearest forest, were given higher multipliers than the small scale influence characteristics, e.g. type of ground (see Table 3.).

Table 3: The crossing structure characteristics, their values and multipliers for the values assigned in the GIS analysis

Characteristic	Crossing Value	Multiplier
Number of lanes on the highway/ motorway	6: 2 lanes 5: 3 lanes 4: 4 lanes 3: 5 lanes 2: 6 lanes	4
Utilization of the crossing	1: No 2: Water 3: Cycle/Pedestrian path 4: Farm road 5: Road 6: Railway 7: Road & railway	2
Permeability value	1: > 4.10 2: > 1.09 ≤ 4.10 3: > 0.37 ≤ 1.09 4: > 0.09 ≤ 0.37	2
Type of ground	1: Natural 2: Semi-natural 3: Artificial	1
Leading structure	1: Yes 2: No	3
Road Fencing	1: Yes 2: Yes, one direction 3: No	1
Distance to nearest hiding structure	Meters	2
Distance to nearest forest >1ha	Meters	4
Total daily traffic cars	1: >24800 2: >18000 ≤ 24800 3: >12000 ≤ 18000 4: >8700 ≤ 12000 5: >4300 ≤ 8700 6: ≤ 4300	4
Total daily traffic trucks	1: >4300 2: >2000 ≤ 4300 3: >1600 ≤ 2000 4: >1300 ≤ 1600 5: >600 ≤ 1300 6: ≤ 600	4

After the crossing structure end value calculation the weighted overlay was performed in ArcGIS for the land use, obtained from CORINE data (cell size: 100mx100m; 2006) (EEA, 2014), roads and crossing structure layers, with influences of 30%, 30% and 40% respectively. Additionally, the values within each layer were reclassified (Table 4). The LCP analysis was performed separately to each successful lynx crossing event.

Table 4: Data layers used in the weighted overlay in GIS with the reclassified values and influence weight

Layer	Reclassified value	Weight
Land use	2: Forest 3: Scrub and/or herbaceous vegetation associations 4: Heterogeneous agricultural area 5: Permanent crops & Arable land 6: Pastures 7: Open spaces with little or no vegetation & Inland wetlands 8: Inland waters 9: Artificial, non-agricultural vegetated areas & Mine, dump and construction 10: Industrial, commercial and transport units & Urban fabric 0: No data	30%
Roads	10: Other roads 15: Motorways 20: Highways 0: No data	30%
Crossings	Divided into 10 even categories -10: highest values -9: second highest values -8: third highest values etc. 0: No data	40%

To analyse the crossing structure characteristics, only structures within a buffer, where a crossing structure was expected to have been used, according to the GIS analysis, were used for further SPSS analysis. Within these buffers the crossing structures expected, according to the LCP analysis, to have been used (n=13) as well as the structures expected not to have been used (n=124) were selected. In SPSS, data of these crossing structures were tested with a statistical significance level of 0.05. All the variables were tested for normal distribution of the data separately for the data on the expected used crossing structures and un-used structures (Kolmogorov-Smirnov). Since the data were not normally distributed (P<0.05), even after transformation with the Log10 value, and did not meet all the assumptions of parametric tests, the nonparametric Mann-Whitney U –test was used for the data analysis. The crossing type was analysed by comparing the frequencies of each type of crossing structure between the expected used structures and un-used structures.

The crossing structures at the lynx mortality sites were analysed with the frequency values due to a low sample size (n=5). In addition, the data on the lynx mortality locations (n=5) were included in the analysis of the distance to nearest hiding structure, forest, tree patch and traffic.

Results

Most likely crossing routes

From a total of 25 LCP analysed lynx road crossing events, where a total of 222 times a crossing structure was available, five occurred at highways and 20 occurred at motorways. Since the LCP analysis is based on computer calculation and does not display the reality all results are predictions. However, the crossing events that were expected to have used or not used a crossing structure will be referred in the text as *used* or *not used*. According to the LCP analysis 13 crossing events *used* a crossing structure. In two of these crossing events over passages were *used* and 11 times under passages were *used* (Figure 5). Since two under passages were *used* more than once for different crossing events, only seven different under passage structures were *used*. Out of the 13 crossing events, where *no* structure were *used*, ten occurred at two lane motorways and three on four lane roads. All of these 13 events, where a structure was *not used*, forest reached or overlapped the road. See Table 5 for an overview of the LCP results.

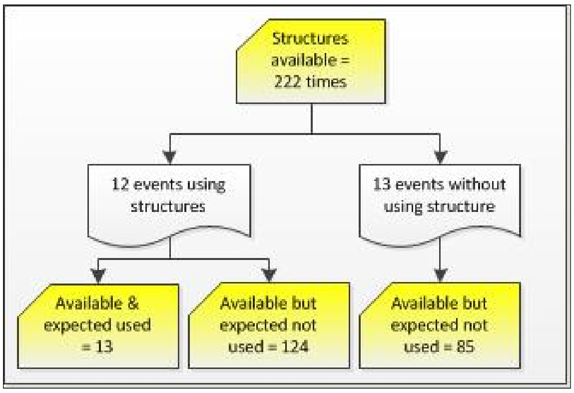

Figure 5: Overview of number of crossing events, total available crossing structures (N=222) and subdivision between crossing events that *used/ not used* a crossing structure

Table 5: Overview of the LCP results of the 25 crossing events with the number of lanes, utilization of crossing structure and occurrence of forest

Road	No of lanes	Lynx	Structure *used* (Y) / *not used* (N)	Crossing type: under passage (UP) / over passage (OP)	Forest near road: yes (Y) / no (N)
B243	4	F4	Y	OP	Y
B243	4	F4	N	-	Y
B248	2	F4	N	-	Y
B248	2	F4	N	-	Y
B248	2	F4	N	-	Y
B248	2	F4	N	-	Y
B248 /B82	2/2	M7	N/Y	-/UP	Y/Y
B248 /B82	2/2	M7	N/Y	-/UP	Y/Y
B248 /B82	2/2	M7	N/Y	-/UP	Y/Y
B248 /B82	2/2	M7	Y/Y	UP/UP	Y/Y
B82	2	M7	Y	UP	Y
B82	2	M7	N	-	Y
B82	2	M7	N	-	Y
B82	2	M7	N	-	Y
B82	2	M7	N	-	Y
B82	2	M7	N	-	Y
B82	2	M7	N	-	Y
B243	4	M2	Y	UP	Y
B243	4	M2	Y	UP	Y
B243	4	M2	N	-	Y
A38	4	M2	Y	UP	Y
A38	4	M2	Y	UP	Y
A38	4	M2	N	-	Y
A7	4	M6	Y	OP	Y
A7	4	M6	Y	UP	N

In the northern part of the study site three crossing clusters could be defined (Figure 6) according to the roads that were crossed by two different lynx individuals.

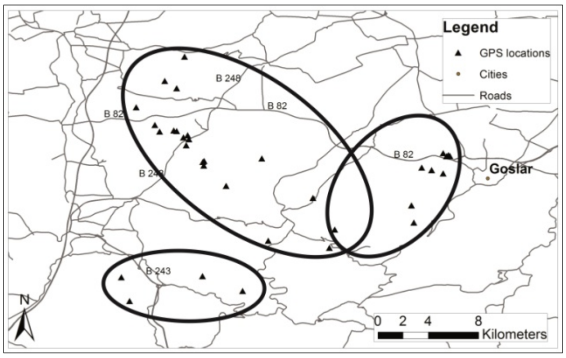

Figure 6: Clusters of GPS locations of road crossing events from lynx F4 and M7 in the northern part of the study area

Figure 7 displays an example of the LCP results of two M2 road crossing events over the highway A38. These crossing events were calculated to have *used* the same under passage and show clearly the forest reaching the road.

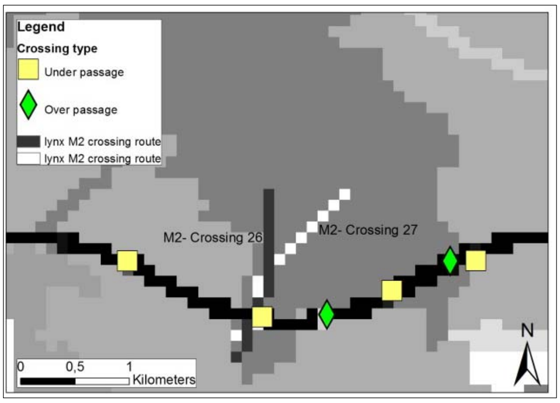

Figure 7: Expected crossing routes of the lynx M2 over the highway A38 *using* twice the same under passage; the dark grey area indicates occurrence of forest overlapping the road

Characteristics of successful crossing sites

All the crossing structures *used* by lynx were either under passages or over passages. The structures available were widely distributed across different crossing structure types. Of these, under passages were the most common structures, while over passages and water tunnels were nearly equally common and viaducts were the least common type of structures. The distribution of the structures *not used* by lynx had a similar frequency across the types of structures. (See Table 6 for details)

Table 6: Frequencies of the crossing structure types for structures *used* and *not used* by lynx during a road crossing event and the distribution of crossing types available (Portion) (N=137)

Type of crossing	*Used* (%) (n=13)	*Not used* (%) (n=124)	Portion from total N (%)
Viaduct	0	5.6	5.1
Water tunnel	0	22.6	20.4
Under passage	84.6	47.6	51.1
Over passage	15.4	24.2	23.4

The differences for the results of the LCP analysis, crossing structures *used* by lynx for road crossings and the structures *not used* by lynx, were analysed. The leading structures on both sides of the crossing structures were more present (West/South: M-W; *U*=548.5, *Z*=-2.2, *P*=0.028; East/North: M-W; *U*=548.5, *Z*=-2.2, *P*=0.028) at the crossing structures *not used* by lynx. Also, the mean distances to nearest forest on both sides of the crossing structures were significantly (West/South: M-W; *U*=435, *Z*=-2.725, *P*=0.006; East/North: M-W; *U*=269, *Z*=-3.945, *P*<0.001) longer at the structures *not used* by lynx. The distance to nearest hiding structure on the West/South side was found to be significantly longer at the structures *used* by lynx (M-W; *U*=324, *Z*=-3.498, *P*<0.001). The utilization, permeability, distance to nearest hiding structure on the East/North side, distance to nearest tree patch, road fencing on either side, the type of ground of the crossing structures and the car or truck traffic did not show significant differences (P>0.05) between the structures *used* and *not used* by lynx. (See Table 7 for details)

Table 7: Crossing structure characteristics with significant differences between crossing structures *used* by lynx and *not used* by lynx during a road crossing event (N=137)

Variable	*Used* (n=13)	*Not used* (n=124)	*P*
Leading struct. present West/South (%)	7.7	37.9	0.028
Leading struct. present East/North (%)	7.7	37.9	0.028
Dist. (m) near hiding struct. West/South (mean)	11	5	<0.001
Dist. (m) near forest West/South (mean)	199	730	0.006
Dist. (m) near forest East/North (mean)	166	882	<0.001

Characteristics of road mortality sites

The lynx mortality sites were also investigated for indications of the crossing structure suitability. There were five locations of lynx mortalities with a total of five crossing structures within these sites. Two of the lynx mortality sites were at highways and three at motorways, with four of these mortalities at four lane roads and one at a two lane road. The crossing structures at these sites had a large variety in all the characteristics. At four out of five mortality sites forest reached the road at least on one side of the road, while road fencing was present at two mortality sites (B4 and A38). Furthermore, no clear similarities were found and therefore no indications on the crossing structure suitability or unsuitability were found on this data.

Discussion

Results

As a conclusion, it is suggested that the lynx dispersal over high traffic roads in the Western Harz region is expected to utilize road crossing structures as nearly 50% of the successful events *used* a crossing structure. However, some crossing characteristics are considered to have a higher importance. A short distance to forest from the crossing structure is considered to increase the lynx use of the structure. Also, the lynx utilization of crossing structures is predicted to be positively related to the increasing number of lanes on the road. Hence, smaller motorways with lower number of lanes could permit lynx road crossing without the use of crossing structures and wider roads with more lanes would act more as a barrier for the lynx.

The forested areas directing the lynx road crossing habits was indicated with the LCP results of this study. Thus, the use of crossing structures was higher in the areas where forest leads to the road to be crossed and more importantly, continued to the other side of the road. Additionally, at all of the 13 crossing events, where a crossing structure was *not used*, the forest led the lynx toward a road section where no structures were available. Schadt et al. (2002) confirmed that large forest areas are the most suitable habitat for lynx. Additionally, natural habitat patches are important for lynx dispersal and high distances between natural, including forested, areas could be harmful for lynx dispersal

(Jedrzejewski et al., 2009). Therefore, the calculated high use of forested areas is an important indicator also toward the use of road crossing structures, which was supported by the results as distance to nearest forest was significantly lower at the *used* than *not used* road crossing structures.

The leading structures were significantly more present and the mean distance to nearest hiding structure on one side of the crossing structure (West/South) was significantly shorter at crossing structures which were *not used* by lynx. Astoundingly, the results were contradicting to expectations based on literature. Linear waterways and vegetation could bring guidance to the animal movement (Klar et al., 2009) and cover connections between the crossing and the animal's habitat improve the use of crossing structures as a corridor (Clevenger & Huijser, 2011; Rodriguez et al., 1997; Wölfel & Krüger, 1991). Additionally, similar studies show that wildcats prefer cover at the entrance of a crossing structure (Rodriguez et al., 1997). Therefore, leading structures could raise the suitability of the crossing structures where these characteristics are present and the distances are shorter. This contradiction could be explained by a choice of method during data collection: when forest reached within the 150m distance from the crossing structure, no additional leading structures were taken into account and therefore, could show a lower presence of leading structures in the results. However, the presence of forest did not affect the measurements of the distance to nearest hiding structure.

Any of the other crossing structure characteristics did not show significant differences between the used and not used crossing structures. This could be due to a low sample size (N=222) based on crossing events of only four different lynx individuals within the same area.

Animal mortality due to car accidents during road crossing depend on different factors, such as the traffic volume, speed of vehicles, the width of the road and the area crossed (Jedrzejewski et al., 2009). Nonetheless, as the results indicated, four of the mortality sites were at locations where the forest reached near the road. This supports the findings of the further analysis: importance of the distance to forest at the road crossing location. It could be seen that the lynx were directed toward the road by the presence of forest.

Road fencing was found to be present at two mortality sites. Surprisingly, this is contradicting to the findings of other studies which indicate that as the lynx approaches the road, wildlife fencing could direct the movements away from roads and therefore decrease road mortalities (Clevenger et al., 2001; Clevenger & Huijser, 2011; Klar et al., 2009). Therefore, it could be suggested that the fence does not act as an insuperable barrier for lynx.

Due to the low number of the lynx mortalities on roads, it was not possible to compare the differences between the crossing structures within the mortality sites and the crossing structures at the successful lynx road crossing sites. With a possible higher sample size, it is suggested that the differences between the mortality sites' and the successful crossing sites' crossing structures should be compared in order to find specific structure characteristics to possibly indicate the suitability for lynx. It is also unknown whether lynx have crossed the road at the same site prior to the mortality event. Thus, it could be impractical to classify these sites as unsuitable locations if the site has been repeatedly used for successful road crossings and only one event has led to mortality.

Methods

Prior to the study an extensive desktop study and consultation with lynx experts were conducted in order to minimize subjective decisions and improve the objectivity of the study. However, the methodology used in this study could be discussed at some points, especially for the many decisions that had to be made during assigning the values of importance to the characteristics of the crossing structures in LCP analysis, which could have affected the reliability of the findings.

Traffic volume can act as a barrier for animals (Jedrzejewski et al., 2009; Klar et al., 2009). On high traffic roads the number of wildlife accidents decline due to a high barrier effect of the particular road (Jedrzejewski et al., 2009). Therefore, for the LCP analysis the different types of roads were divided into three categories (highways, motorways, and other rural roads) and were given a value based on their barrier effect for the lynx road crossing. However, a more precise definition of the roads' barrier effect could be achieved by classifying the road layer according to traffic frequency for each road section, since the traffic volume is highly correlated with road mortalities on medium size roads and motorways. In the weighted overlay the factor layers were given the following influences: land use 30%, roads 30% and crossing structures 40%. Using these influence values combined the forest and shrub areas and provided the same value in the LCP to these land use types. Hence, the useful areas for lynx dispersal were combined. In addition, with this decision land use and roads held the same influence, while the crossing structures had a stronger influence. This was suitable to this study as the aim was to investigate the utilization of crossing structures in lynx dispersal. Nevertheless, as mentioned previously, the results pointed that the forested land use did have a very strong influence on the lynx dispersal route. This could point the high importance of the land use, rather than the crossing structure characteristics in the LCP analysis and should be taken into consideration in further lynx road crossing studies. The large cell size (100mx100m) of the land use in the GIS should also be deliberated, as some detail could have been overlooked during the LCP analysis. A more detailed dataset could provide more accurate results. Furthermore, the presence of insuperable barriers, such as canals, could have limited the availability of crossings structures to lynx and therefore, affected the suitability of these structures. However, this was prevented by confirming the availability of all structures from satellite images.

One of the M2 structure use over the highway A38 is a good indicator on the strength of the LCP analysis. The experts of the Luchsprojekt Harz suggested prior to the analysis that the lynx would have crossed the road by using an under passage near the lynx' second GPS location (Luchsprojekt Harz, 2014). As the result of the LCP analysis suggested M2 would have indeed *used* the same under passage as suggested by the experts, this could strengthen the validity of this analysis.

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Appendices

Appendix I: Step descriptions (Preparation for GIS analysis & GIS analysis)

Preparation of layers

1. **Input:** RoadClip (NOT IN THE MODEL BUILDER)
   Tool: Add field:
   Name :RoadValue; Field type: short
   Output: RoadClip

2. **Input:** RoadClip (NOT IN THE MODEL BUILDER)
   Tool: Select by Attribute:
   ref= A4 OR ref= A7 OR...(select all roads with ref= A+"number'')
   Output: RoadClip

3. **Input:** RoadClip (NOT IN THE MODEL BUILDER)
   Tool: Field Calculator: RoadValue=3
   Output: RoadClip

4. Repeat steps 3. and 4. With the following values (NOT IN THE MODEL BUILDER):
   a. All ref=B+"number">RoadValue=2
   b. All ref=K+"number" OR ref=L+"number" >RoadValue=1
   Output: RoadClip

5. **Input:** RoadClip
   Tool: Polyline to Raster:
   Value field: RoadValue; Cellsize: g100_06.tif (CORINE data)
   Output: Roads

6. **Input: Roads** (NOT IN THE MODEL BUILDER)
   Tool: Export Data: Spatial Reference: Data Frame (Current)
   Output: Roads1.tif

7. **Input:** g100_06.tif (rename into:CorineLanduse2006-g100_06) (NOT IN THE MODEL BUILDER):
   Tool: Joint
   Joint table: clc_legend.xls;
   Joint field: Value
   Output: CorineLanduse2006

8. **Input:** CorineLanduse2006-g100_06
   Tool: Clip (Data management)
   Output Extent: RoadClip
   Output: CorineClip

9. **Input:** CorineClip
   Tool: Reclassify; Reclass field: LABEL2;
   a. Forest=0
   b. Scrub and/or herbaceous vegetation associations=1
   c. Heterogeneous agricultural area=2
   d. Permanent crops; Arable land=3
   e. Pastures=4
   f. Open spaces with little or no vegetation; Inland wetlands=5
   g. Inland waters=6
   h. Artificial, non-agricultural vegetated areas; Mine, dump and construction=7
   i. Industrial, commercial and transport units; Urban fabric=8
   Output: CorineRec

10. **Input:** CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Editor (drag points onto Roads1 raster if they are displayed next to it)
    Output: -

11. **Input:** CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Edit: Create feature
    (place additional points where the Crossings.tif doesn't overlay the whole road); give points the corresponding ID of the crossing in the Attribute Table)
    Output: -

12. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Add field: Name: GroundVal; Field type: short
    Output: -

13. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Select by Attribute: Ground1=1OR Ground1=7 OR Ground1=8
    Output: -

14. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Field Calculator: GroundVal=1
    Output: crossingsr2.tif

15. **Repeat** steps 2. and 3. with the following values (NOT IN THE MODEL BUILDER):
    Ground1=2 OR Ground1=3 OR Ground1=6 OR Ground1=9 --> GroundVal=2;
    Ground1=4 OR Ground1=5--> GroundVal=3
    Output: -

16. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Reclassify; Reclass field: Permeabilit; Classify: Quantiles; Classes: 5; Reverse values
    Output: -

17. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Add field: Name: PermVal; Field type: short
    Output: -

18. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Select by Attribute: Permeabilit≤ 0.09
    Output: -

19. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Field Calculator: PermVal=5
    Output: -

20. **Repeat** steps 7. and 8. With the following values (NOT IN THE MODEL BUILDER):
    Permabilit> 0.09 AND Permabilit≤ 0.37--> PermVal=4;
    Permabilit> 0.37 AND Permabilit≤1.09 --> PermVal=3;
    Permabilit> 1.09 AND Permabilit≤4.10 --> PermVal=2;
    Permabilit> 4.10 --> PermVal=1
    Output: -

21. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Reclassify; Reclass field: DayTrCar; Classify: Natural Breaks (Jenks); Classes: 6; Reverse values
    Output: -

22. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Add field: Name: TrafValCar; Field type: short
    Output: -

23. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Select by Attribute: DayTrCar≤ 4300
    Output: -

24. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Field Calculator: TrafValCar=6
    Output: -

25. **Repeat** steps 12. and 13. With the following values (NOT IN THE MODEL BUILDER):
    DayTrCar>4300 AND DayTrCar≤ 8700 --> TrafValCar=5;
    DayTrCar>8700 AND DayTrCar≤ 12000--> TrafValCar=4;
    DayTrCar>12000 AND DayTrCar≤ 18000 --> TrafValCar=3;
    DayTrCar>18000 AND DayTrCar≤ 24800 --> TrafValCar=2;
    DayTrCar>24800 --> TrafValCar=1
    Output: -

26. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Reclassify; Reclass field: DayTrTru; Classify: Natural Breaks (Jenks); Classes: 6; Reverse values
    Output: -

27. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Add field: Name: TrafValTru; Field type: short
    Output: -

28. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Select by Attribute: DayTrTru≤ 600
    Output: -

29. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Field Calculator: TrafValTru=6
    Output: -

30. **Repeat** steps 17. and 18. With the following values (NOT IN THE MODEL BUILDER):
    DayTrTru>600 AND DayTrTru≤ 1300 --> TrafValTru=5;
    DayTrTru>1300 AND DayTrTru≤ 1600 --> TrafValTru=4;
    DayTrTru>1600 AND DayTrTru≤ 2000 --> TrafValTru=3;
    DayTrTru>2000 AND DayTrTru≤ 4300 --> TrafValTru=2;
    DayTrTru>4300 --> TrafValTru=1
    Output: -

31. **Input**: CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Add field: Name: EndVal; Field type: Double; Precision:18; Scale: 1
    Output: -

32. **Input:** CrossingsAll (NOT IN THE MODEL BUILDER)
    Tool: Add Field: EndValue ([NoLanesCod]*4+ [DayTrCar]*4+ [DayTrTru]*4+ [DistForeWS]*4+ [DistForeEN]*4+ [LeadStrA]*3+ [LeadStrB]*3+ [Utilizat_1]*2+ [DisNeStrWS]*2+ [DisNeStrEN]*2+ [Permabilit]*2+ [Ground1]+ [FenceA]+ [FenceB])
    Output: CrossingsEndval

33. **Input:** CrossingsEndval NOT IN THE MODEL BUILDER)
    Delete all surplus fields (text)
    Output: CrossingsEndval

34. **Input:** CrossingsEndval
    Tool: Point to Raster
    Value field: EndValue1; Cellsize: Roads1.tif
    Output: Crossfinalall

35. **Input:** Crossfinalall (NOT IN THE MODEL BUILDER)
    Tool: Export Data: Spatial Reference: Data Frame (Current)
    Output: Crossfinal

36. **Input:** F4Cr12Buf (NOT IN THE MODEL BUILDER)
    Tool: New>Shapefile (Name: F4Cr12Pol; Feature Type: Polygon)
    Output: F4Cr12Pol

37. **Input:** F4Cr12Pol (NOT IN THE MODEL BUILDER)
    Tool: Editor>Create Feature (rectangle; overlap polygon surface)
    Output: F4Cr12Pol

38. Repeat step 17. for the following buffer (NOT IN THE MODEL BUILDER):
    F4Cr13; F4Cr17; F4Cr18; F4Cr19; M2Cr23; M2Cr26; M6Cr21; M6Cr22; M7Cr10; M7Cr11
    Output: "CrNo"Pol

Least cost path analysis

Model: UnionExtractMultiple

1. **Input**: F4Cr15Buf
   Tool: Union; Input features: F4Cr15Buf
   Output: F4Cr15BufUn

Multiple model builder was used for performing the step 1 for: F4Cr15, F4Cr16, F4Cr20, M2Cr24, M2Cr25, M2Cr27, M2Cr28, M7Cr1-Cr9

2. **Input**: F4Cr15BufUnion, F4Cr17Pol
   Tool: Extract by Mask; Input raster: Crossfinal; Feature Mask data: F4Cr15BufUnion
   Output: F4Cr15sel, F4Cr17sel

Multiple model builder was used for performing the step 2 for all "BufUn" and "Pol" shapefiles

(NOT IN MODEL BUILDER)

3. **Input**: F4Cr15sel
   Tool: Weighted Overlay;
   Input raster: CorineRec; Input field: Value; 0=1, 1=2, 2=3, 3=4, 4=5, 5=6, 6=7, 7=8, 8=9, No Value=20
   Input raster: roadraster1.tif; Input field: Value; Scale Value: 1=1, 2=2, 3=3, No Value=20
   Input raster: F4Cr15sel; Input field: ENDVALUE1; Scale value: Lowest ENDVALUE1=1, next=2 etc., No Value=20
   Set Influence: CorineRec: 50%, roadraster1.tif: 25%, F4Cr15Sel: 25%
   Output: WeighF4Cr15

Model: LeastCostMultiple

4. **Input**: WeighF4Cr15
   Tool: Cost Distance
   Input raster: F4Cr15End (Endpoint); Input cost raster: WeighF4Cr15
   Output: CostDistF4Cr15
   Output backlink raster: backlF4Cr15

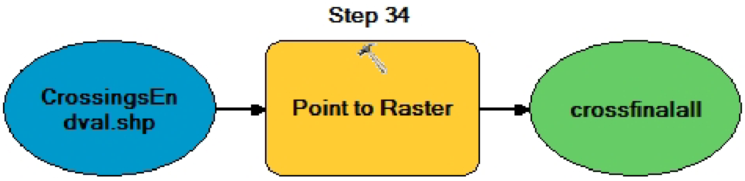
Multiple model builder was used for performing the step 5 for all "wei" raster files and "End" shapefiles

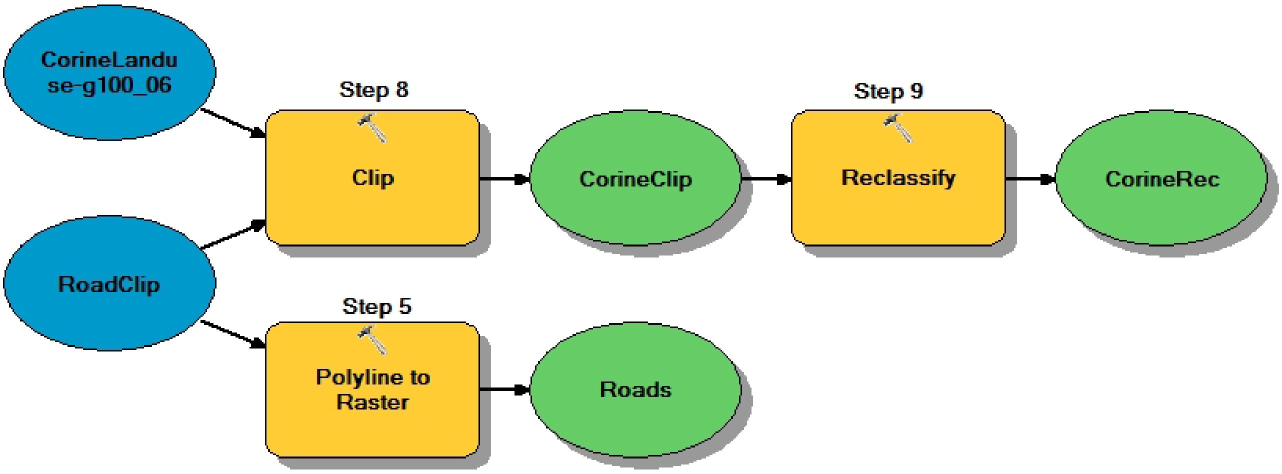
5. **Input**: F4Cr15Start (Startpoint)
   Tool: Cost Path
   Destination field: FID; Input cost distance raster: CostDistF4Cr15; Input cost backlink raster: backlF4Cr15
   Output: CostPaF4Cr15

Multiple model builder was used for performing the step 6 for all "Start" shapefiles with "codi" & "backl" raster files

Appendix II: Models of GIS analysis

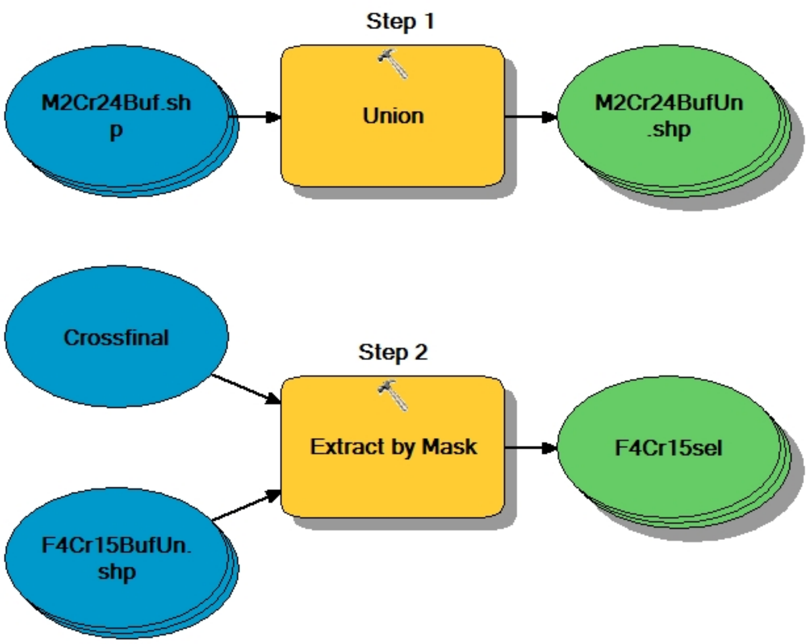
Preparation of layers





Least cost path analysis

<u>**Model: UnionExtractMultiple**</u>



Least cost path analysis

Model: LeastCostMultiple