Management and Conservation Article

Effects and Mitigation of Road Impacts on Individual Movement Behavior of Wildcats

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ABSTRACT Roads can affect the persistence of wildlife populations, through posing mortality risks and acting as barriers. In many countries, transportation agencies attempt to counterbalance these negative impacts. Road mortality is a major threat for European wildcats (*Felis silvestris*); therefore, we tested the effectiveness of a newly developed wildcat-specific fence in preventing wildcat mortality along a new motorway. We hypothesized that such a fenced motorway would at the same time be a significant barrier to wildcats and may at worst result in 2 isolated populations. We used radiotracking data of 12 wildcats, resulting in 13,000 fixes, to investigate individual movement behavior during and after construction of a new motorway in southwestern Germany. The motorway was fenced with the wildcat-specific fence and included crossing structures, not especially constructed for wildlife. Additionally we collected road kills on stretches of the same motorway with various types of fencing. A rate of 0.4 wildcat kills/km/year on the motorway, which was traveled by 10,000 vehicles/day and fenced with a regular wildlife fence, was reduced by 83% on stretches with wildcat-specific fencing. Of the available crossing structures, wildcats preferred open-span viaducts. Road underpasses were used but hold a mortality risk themselves. As opposed to our expectations, the fenced motorway (fenced with wildcat fence) posed only a moderate barrier to wildcats. Individuals were hindered in their daily routine and some stopped crossing completely but others continued crossing regularly. The adaptation of spatial and temporal behavior to traffic volume and location of crossing structures has an energetic cost. Hence, we suggest that only a small number of major roads can be tolerated within a wildcat's home range. To meet the demands of the European Habitats Directive, we recommend installing the wildcat fence in wildcat core areas along motorways to reduce wildcat mortality. We suggest that fences should incorporate safe crossing structures every 1.5–2.5 km. Our findings in terms of fencing design and crossing structures can be used by transportation agencies for an effective reduction of road mortality and barrier effect for carnivores. (JOURNAL OF WILDLIFE MANAGEMENT 73(5):631–638; 2009)

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Carnivores, because of their large spatial requirements, are impacted by roads and traffic in the human-dominated landscape of Central Europe. However, very little is known about how species survive in and use environments affected by roads (Ramp et al. 2006). Roads can have direct negative effects on wildlife such as mortality, hindrance to movement, disturbance, and habitat loss and indirect effects such as increased human access and disturbance (Mader 1984, Forman and Alexander 1998, Spellerberg 2002, Roedenbeck et al. 2007). Wildlife mortality due to traffic has increased during recent decades and is found to be the main threat for some medium-sized carnivores in Central Europe (Van der Zee et al. 1992, Clarke et al. 1998, Philcox et al. 1999, Hauer et al. 2002).

The effects of roads on crossing behavior and as physical barriers to carnivores are not clear and may depend on traffic volume as well as design and location of roads. Often, dispersers are more sensitive to major roads than are resident animals and refuse to cross (Zimmermann 2004). Other authors describe major highways and motorways as barriers for dispersing as well as resident animals (Beier 1995, Breitenmoser-Würsten et al. 2001, Kaczensky et al. 2003, Riley et al. 2006).

To counterbalance negative effects of roads, the use and effectiveness of mitigation measures are under investigation. To prevent animals from entering the road, fencing is the method of choice because fencing has been effective in reducing road mortality for some species (Clevenger et al. 2001). However, for species with the ability to climb or jump, ordinary wildlife fences provide little or no obstacle. Therefore, more effective fence designs have been requested (Rodriguez et al. 1997, Gloyne and Clevenger 2001, Cain et al. 2003). Fencing is also a controversial subject, because without crossing structures, fences increase the barrier effect of roads (Jaeger and Fahrig 2004).

Crossing structures for wildlife can enhance permeability of roads. Typically, use of such structures by medium to large mammals is monitored using track surveys (e.g., Yanes et al. 1995, Rodriguez et al. 1997, Ng et al. 2004, Mata et al. 2005). These data contain no information on ability of individuals to include the new road into their home ranges or if there are additional energy costs associated with the new road. To answer these questions, individual behavior must be observed. To date, little research has investigated fine-scale movements of individual animals in relation to roads (Rondinini and Doncaster 2002, Dickson et al. 2005).

Wildcats (*Felis silvestris*), once widely distributed throughout Europe, have suffered significant reduction in their original range due to extensive hunting and trapping, resulting in fragmented and small populations (Piechocki

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Table 1. Frequency of detected crossing events over the A60 motorway of individual wildcats observed in Rhineland-Palatinate, Germany, in 2001–2005.

Wildcat no.	A60 without traffic and fence (phase 1)					A60 with traffic and fence (phase 2)				
	Obs crossings	Locations	Days	Crossings/ 100 locations	Crossings/ 10 days	Obs crossings	Locations	Days	Crossings/ 100 locations	Crossings/ 10 days
M1	4	891	152	0.45	0.26					
M4	2	578	124	0.35	0.16					
F3	57	884	156	6.45	3.65					
F1	33	828	120	3.99	2.75	75	2,184	251	3.43	2.99
F2	3	350	45	0.86	0.67	18	802	154	2.24	1.17
M5	112	2,219	241	5.05	4.65	13	229	31	5.68	4.19
F4	6	381	69	1.57	0.87	11	256	63	4.30	1.75
F5	7	282	57	2.48	1.23	0	413	77	0.00	0.00
F6	21	789	112	2.66	1.88	0	156	28	0.00	0.00
M2						8	728	102	1.10	0.78
M6						16	761	102	2.10	1.57
M3						2	153	31	1.31	0.65
All cats	182	4,849	644	3.75	2.83	141	5,529	808	2.55	1.75

1990). Despite a slow recovery of some populations, wildcats are still a species of conservation concern and are, therefore, listed in the European Habitats Directive (Council of Europe 1992, appendix IV). Beside habitat degradation and hybridization with feral cats, road mortality is a major threat for this species in Central Europe (Stahl and Artois 1995, Pierpaoli et al. 2003, Lecis et al. 2006). Knowledge about the wildcat's behavior and spatial requirements is still scarce and controversial.

In many countries traffic agencies are required to implement measures to counterbalance negative effects of roads on the environment. In the European Union, the European Habitats Directive prohibits deliberate killing and mandates conservation measures so that incidental killing does not have a significant negative effect on species listed in annex IV (Council of Europe 1992). Therefore, during official approval of a new motorway through wildcat habitat, a fence that prevented wildcat road mortality was needed (Knapp et al. 2000, Klar et al. 2008). During construction and during the first years of operating this motorway, we investigated effectiveness of a wildcat-specific fence at reducing mortalities caused by automobile strikes. This wildcat fence was designed to prohibit wildcats from crossing the road except at crossing structures. Our objectives were to find weaknesses in fence construction and to be able to make recommendations for further improvement of fencing designs and crossing structures. We hypothesized that despite the presence of crossing structures major roads, particularly a fenced motorway, would pose a significant barrier to wildcats and at worst result in 2 fragmented populations.

STUDY AREA

The study area was situated in southwestern Germany (50°3′N, 6°39′E) and was determined by the position of the A60 motorway from Belgium to Wittlich. This road section was located in the Eifel region. Human density in this rural area was about 70 inhabitants/km^2. Elevation in the study area ranges from 200 m to 450 m. The study area was 37% forested. In the western part of the study area a forest of about 25 km^2 was connected to another forested area to the north, which was dissected by the A60 motorway. The eastern part of the study area was characterized by agriculture on the plateaus and steep forested creek valleys. Wildcats were present throughout the area. Road density was 1.2 km/ km^2. Within the cats' home ranges, 4 road types were present: 1) The A60 motorway under construction, then later 2) the completed A60 with 10,000 vehicles/day and 600 vehicles/hour in the daytime and 100 vehicles/hour at night (Landesbetrieb Straßen und Verkehr Rheinland-Pfalz 2005), 3) the B50 highway (2,500 vehicles/ day), and 4) local roads K7 and K47 (200–300 vehicles/day).

METHODS

Wildcat Data

We monitored wildcats along the A60 motorway during 2 phases: phase 1, construction (Feb 2001–Nov 2002), started when the track for the A60 motorway had been cleared. Phase 2, traffic and fence (Dec 2002–Feb 2005), started when the motorway was opened for traffic and the fence was finished. We collected all wildcat mortality within the study area when reported by motorway authorities, passers-by, or ourselves during phase 2. We mapped the location of each mortality, and examined the dead animal to ensure that it was a wildcat and not a feral cat. We could not detect all mortalities, because unmarked injured wildcats could have left the vicinity of the road to die.

We captured wildcats with wooden live-traps baited with ground valerian root within a 10-km-long and 800-m-wide stretch along the A60 motorway. During capture periods, we checked traps twice per day at dawn and dusk. We immobilized cats intramuscularly with xylacin and ketamin and then sexed, weighed, measured, marked them with transponders, and tagged them with radiocollars (60 g; Wagener, Köln, Germany). Between January 2001 and February 2005 we caught and radiotracked 12 wildcats (6 M, 6 F) for 3–30 months each ($\bar{x} = 15.5$ months, SE = 2.49, $n = 12$) before transmitters failed. We monitored 3 wildcats during only phase 1, 6 wildcats during phases 1 and 2, and 3 wildcats during only phase 2 (Table 1). We

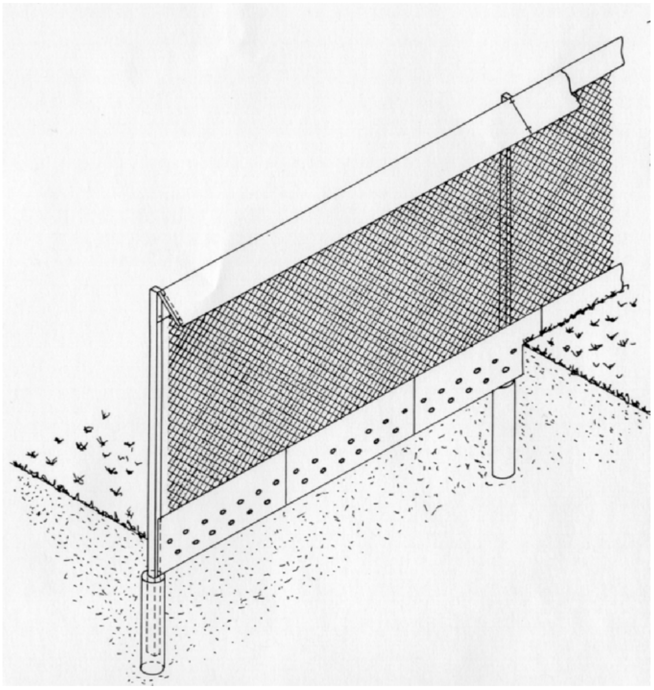

Figure 1. A special fence to prevent wildcats from entering the road was installed at the motorway A60, Germany, in 2001 for the first test in the field. The wildcat fence consisted of a metal sheet as 50-cm overhang, was 2 m high, mesh size was 5 × 5 cm, and a 30-cm plastic board was dug in the earth. Designed by Landesbetrieb Mobilität Rheinland-Pfalz, Koblenz, Germany.

obtained locations using triangulation or by direct sightings (White and Garrott 1990). We tested accuracy of radio-locations by locating radiocollars hidden in different known heights and positions within the study area. The estimated error radius was <100 m in 95% of trials. We achieved this high level of accuracy due to the dense network of dirt roads, allowing us to get within 10–500 m of tracked cats. We located collared animals ≥8 days/month once or twice at daytime (randomly between 0800 hr and 2000 hr). When we located a cat, researchers stayed ≥15 minutes to obtain 2 locations to check for movement. We also followed each animal continuously for ≥2 nights/month. Nighttime tracking sessions occurred between 2000 hours and 0800 hours during the main activity phase of wildcats (Stahl 1986, Liberek 2002). Depending on number of researchers available, we followed individual cats for 4–12 hours. Shorter tracking periods started randomly within the night. We took locations every 15 minutes. When wildcats approached roads, we tried to remain as close as possible without disturbing the cats to identify the exact location of crossing. This monitoring regime resulted in an average of 24 nighttime tracking sessions per cat, each with 16–48 locations, and in 96 daytime tracking sessions per cat, each with 2–8 locations. In total, we collected approximately 13,000 locations.

Effectiveness of Fences in Preventing Mortality

We compared wildcat road-kill numbers on 3 motorway stretches with various types of fencing using a control–impact (CI) design (Green 1979, Roedenbeck et al. 2007). A before (i.e., no treatment) situation was not available because fence and motorway were finished at the same time. The impact site consisted of the wildcat fence, whereas the control sites consisted of a fine-meshed fence and a regular wildlife fence. These 3 stretches were close to each other and all within wildcat habitat (Klar et al. 2008).

The wildcat fence (Fig. 1) was developed in enclosures and this was its first test in the field (Landesbetrieb Mobilität Rheinland-Pfalz, Koblenz, Germany). This fence cannot be climbed, jumped, or dug under by wildcats or other species capable of climbing regular wildlife fences. The mesh size was 5 × 5 cm, height was 2 m, a 50-cm-wide metal sheet hindered animals from climbing over, and a board made of recycled material was dug 30 cm deep into the earth to prevent badgers (*Meles meles*) and foxes (*Vulpes vulpes*) from digging under the fence. All pipes and gutters were hermetically shut with metal gates with distances between staves ≤4 cm. To test if the metal sheet on top was necessary, a section of the A60 was fenced with the same fencing material but without the metal sheet as a climbing guard (i.e., fine-meshed fence). Sections of the A60 in nonforested areas were fenced with a regular wildlife fence, and also the nearby A1/A48 motorway was fenced with a regular wildlife fence. Our study area included 17.4 km of the 2 motorways within the forested area: 6.4 km of wildcat fence, 4 km of fine-meshed fence, and 7.0 km of ordinary wildlife fence (5.1 km on the A1/A48 and 1.9 km on the A60 where forest was only present on one side of the road). We conducted radiotracking along the 10.4-km stretch of wildcat- and fine-meshed fence.

Barrier Effects on Movement Behavior

To investigate if the new, fenced road (including all types of fencing) imposed a barrier to wildcat movement, we compared frequency of road crossing for each individual in a before–after (BA) design as well as CI design. In the BA design we counted road crossings on the A60 motorway under construction (phase 1) and on the finished motorway (phase 2). The before-situation was actually a during situation, because the construction had already begun when we started our study. Data on the situation before construction of the motorway were not available. In the CI design we compared frequency of road crossings on the finished motorway to crossing frequency of random lines within individual home ranges. Additionally we counted crossing rates on all other roads within the study area to compare them with crossing rates on the motorway. We considered a road crossing between 2 consecutive locations as a road-crossing event, no matter how much time elapsed between locations. Thus, the crossing events we considered represent the minimum number of actual crossing events.

For the CI design we delimited the individuals' area of activity, using the minimum convex polygon (MCP; Mohr 1947) method. We calculated MCPs using annual and composite (all data) locations for each wildcat. We distributed 100 random lines within individual MCPs. We

Table 2. Use of crossing structures by wildcats at the A60 motorway in Rhineland-Palatinate, Germany, 2002–2005. Parameters include number of collared cats with access to the structure (within or on border of home range), number of collared cats using the crossing structure, and directly observed crossings by radiotracking per crossing structure.

Crossing structure[a]	No.	Measures[b] (m)	No. of cats access	No. of cats crossing	Obs crossings	Cats cross./cats access	No. of snow-tracks/night	No. of sand-bed tracks/night
Viaduct no. 1	BW 67	335, 44, 29	4	3	8	0.75	0.44	
Viaduct no. 2	BW 78	650, 71, 29	3	2	6	0.67	2.50	
40-m-UP	BW 70	40, 5, 29	5	1	1	0.20	0	0.29
Road UP no. 1	BW 72	9, 4.7, 29	2	1	1	0.50	0.20	
Road UP no. 2	BW 79	14, 4.7, 29	4	1	4	0.25	0.00	
Forest road OP no. 1	BW 66	6, 8, 46	3	1	3	0.33	0.33	
Forest road OP no. 2	BW 71	6, 15, 61	5	0	0	0.00	0.00	

[a] UP = underpass, OP = overpass.
[b] Measures: inner width, clear ht, length.

counted crossing frequencies for random lines (Control) as well as roads (Impact) and adjusted them to line length. We compared means of crossing frequency on random lines to crossing frequencies of roads for each individual with a Wilcoxon matched-pairs test.

A barrier can produce changes in behavior in addition to reduced crossing frequency. Therefore, we examined time of crossing relative to traffic volume and average movement behavior. We calculated the locomotor activity of wildcats for all locations within 30 minutes. We divided the distance between 2 locations by the time difference. We calculated mean speed for every hour of the day and for all cats. To define time of crossing, we considered only crossing events derived from 2 locations within 1 hour.

We calculated crossing events and home ranges using ArcView3.2 and ArcGis9.0 and the Animal Movement extension to ArcView (Hooge and Eichenlaub 1997). We performed statistical tests using R statistical software Version 2.3.0 (R Development Core Team 2006).

Use of Crossing Structures

Suitable crossing structures are important to reduce the barrier effect of a fenced road. Therefore, we investigated wildcat use of and behavior at existing crossing structures. Seven passages, not especially constructed for wildlife, were available within home ranges of monitored cats (Table 2), within forest (wildcat habitat; Klar et al. 2008), and >700 m away from villages. Each of the 2 open-span viaducts had one house within 300 m, but in both cases the house was not visible from the viaducts. To determine which crossing structures were used by wildcats, we considered only crossing events within 15 minutes of the last location. Moreover, assignment to a crossing structure only occurred when the observer was confident regarding location of crossing. Additionally, during the 12 days with snow cover in the study area, we searched for wildcat tracks at all crossing structures. At one crossing structure (40-m-underpass; Table 2), we conducted sand-bed tracking for 81 nights. We also analyzed all radiotracking sessions of >4 hours, when wildcats came close (<50 m) to the motorway, to examine their behavior at crossing structures and at the barrier fence.

RESULTS

Effectiveness of Fences Preventing Mortality

During 26 months of monitoring, 12 wildcats were found dead on the 17.4-km stretch of the motorway. One of the cats was marked (M3). No other sources of mortality were reported. One unmarked wildcat was killed within the 6.4-km stretch of wildcat fence (0.07 wildcat kills/km/yr); the wildcat entered the road at a junction area where the fence terminated. Seven casualties were found in the 7-km section with regular wildlife fence (0.41 wildcat kills/km/yr) and 4 cats were killed on the 4-km test section of the fine-meshed fence (0.44 wildcat kills/km/yr).

Barrier Effects on Movement Behavior

In the first year of phase 1, we monitored 4 cats (1 F, 3 M; Fig. 2), 2 of which (F3, M5) regularly crossed the track of the motorway under construction. In the second year of phase 1 we monitored 6 wildcats (5 F, 1 M), 3 of which (M5, F6, F1) crossed on a regular basis, whereas the 3 others crossed only occasionally. In phase 2 (traffic and fence) 2 female cats (F6, F5) stopped crossing the highway, 2 (F2, F4) continued crossing occasionally, and one male (M5) and one female (F1) continued crossing on a regular basis. Note that crossing over the road was possible along the whole 10.4-km stretch during construction (phase 1) but only possible at viaducts and other crossing structures (all together 1 km long) after fencing (phase 2). Three males (M2, M3, M6) were collared after completion of the motorway in phase 2. All of them crossed the A60 occasionally.

The BA design revealed that crossing rate per day and location was higher during construction (phase 1) than after opening for traffic and complete fencing (phase 2; $\chi^2 = 12.0$, $P < 0.001$) but there were no differences when comparing individuals (Table 1; Wilcoxon signed-rank test: $V = 14$; $P = 0.56$). Relative to random lines within the individual home ranges (CI design), the A60 motorway and the B50 highway were crossed less often by all individual cats (Wilcoxon signed-rank test: $V = 0$, $P = 0.004$; $V = 0$, $P = 0.09$, respectively) than expected under a random distribution. The 2 small local roads, the K7 and K47, as well as the A60 under construction, were crossed randomly (Fig. 3).

Wildcat movement took place mainly between 1700 hours and 0800 hours (Fig. 4). Road crossings took place in an

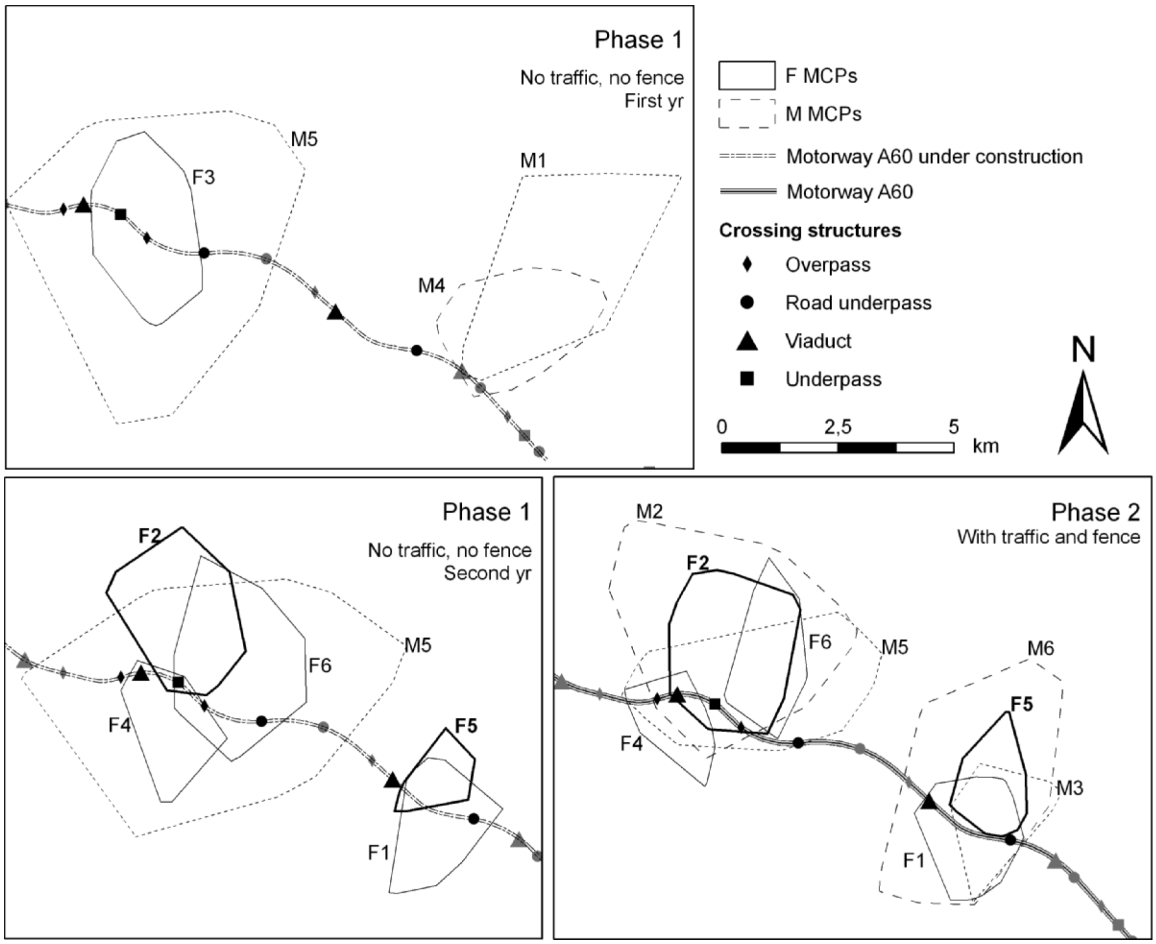

Figure 2. Home ranges (100% min. convex polygons [MCPs]) of 12 collared wildcats in 3 years (2001–2004) in relation to the A60 motorway (approx. 10,000 vehicles/day in the third yr) in Rhineland-Palatinate, Germany. Home ranges are labeled with wildcat identification. Shown in gray are crossing structures we did not consider in the evaluation because of being outside wildcat home ranges in the year with traffic or because of being outside wildcat habitat.

even shorter period at night between 1800 hours and 0600 hours. Peaks of traffic volume were at 1700 hours and 0700 hours on all roads within the study area.

Use of Crossing Structures

During construction (i.e., phase 1) all wildcat crossings took place over the cleared and (during the last months) paved motorway track and under the 2 viaducts (under construction). After fencing (i.e., phase 2), we observed no wildcat crossings of the wildcat fence. In 3 cases observers stated a possible wildcat crossing of the fine-meshed fence but this could not be proven. No data on crossing were available for the regular wildlife fence because we conducted no radiotracking in these areas. Of the 7 crossing structures within the area of the wildcat home ranges (Fig. 2; Table 2), 6 were used by collared wildcats during phase 2. The most frequented crossing structures were the 2 big open-span viaducts. Five of 7 wildcats that had viaducts within their home range used them. All other crossing structures were each used by only one of the observed cats or not at all (forest road overpass no. 2). Snow-tracking showed similar results. The least preferred crossing structures were overpasses for forest roads that went over the motorway.

In phase 2, we conducted 21 continuous radiotracking sessions $\geq$4 hours long in which wildcats came close ($<$50 m) to the motorway. On 12 of these occasions, wildcats directly approached the crossing structure and crossed. On 3 occasions, we observed wildcats detour several hundred meters to a different crossing structure. On another 3 occasions, wildcats turned back from a crossing structure without crossing, and 3 times wildcats stopped in their path $<$200 m from a crossing structure, stayed there during the day, and crossed the next night. We observed detouring and hesitating at all crossing structures except open-span viaducts. Sightings of wildcats near the wildcat fence showed them approaching and turning back as well as walking along the fence to the next hole or crossing structure. Holes in the fence were only present at the beginning and were closed as soon as detected. We observed no other behavior than straight crossing during phase 1 (i.e., before fencing).

DISCUSSION

Effectiveness of Fences Preventing Mortality

The wildcat fence was effective in reducing wildcat road mortality. Mortality was reduced by 83% (N = 12)

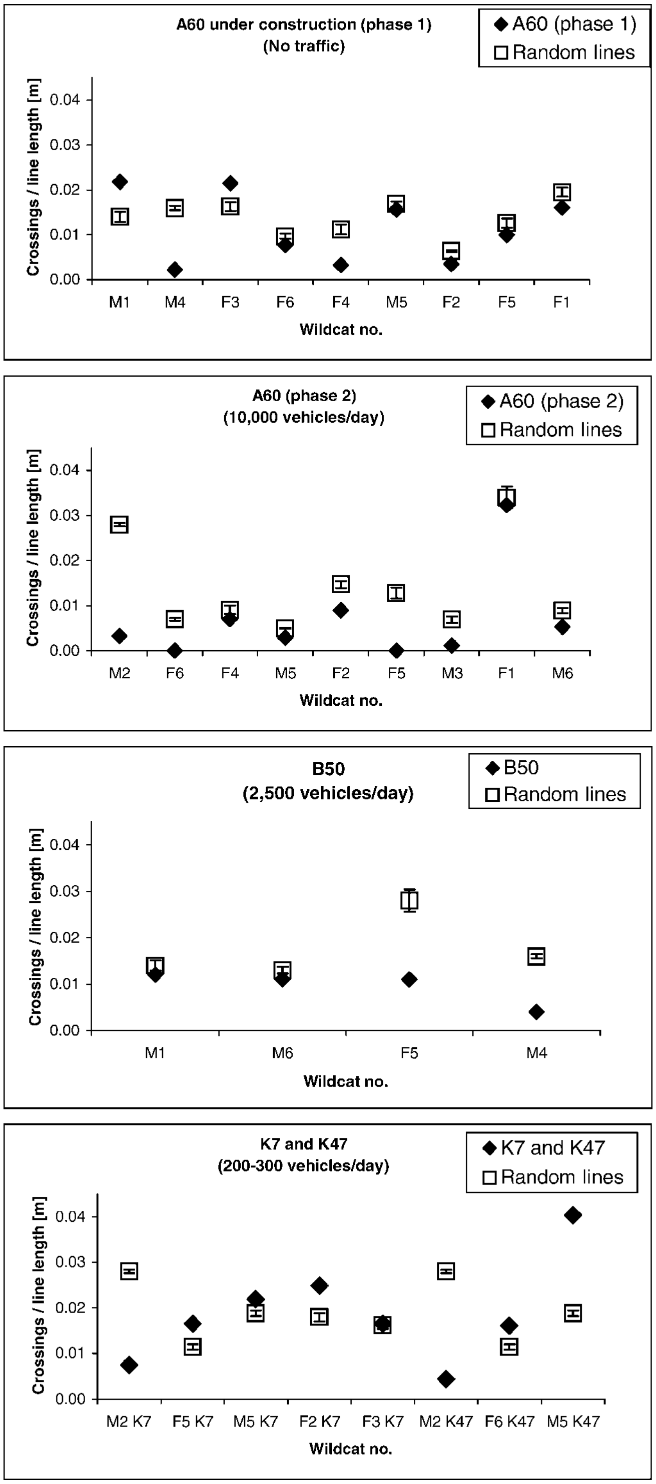

Figure 3. Relative crossing frequencies of individual wildcats over 4 road types compared to random lines within their home ranges in Rhineland-Palatinate, Germany, 2001–2005.

compared to the regular wildlife fence. The simpler fine-meshed fence, which allowed cats to climb over, did not reduce wildcat mortality. Similar to Rodríguez et al. (1997) our direct observations of wildcat movements showed that the regular wildlife fence was no obstacle for wildcats. Problematic points in the wildcat fence were motorway junctions, where the fence was interrupted. Also small holes where the fence was not constructed properly were found and used by wildcats to cross the motorway, indicating that the fence must be meticulously constructed to ensure no holes exist. The actual number of wildcats hit by cars was likely higher than estimated because cats could have been severely injured only to wander away and die undetected.

Home-range sizes and spatial organization of the population suggests 10–12 home ranges along a 10-km stretch of the motorway within forest (Hötzel et al. 2007). A kill rate of 0.4/km, as observed for sections using regular wildlife fencing, would mean that 30–40% of the wildcats living along the motorway (in a 6-km-wide buffer zone) are killed every year. Compensatory mechanisms to offset the impacts of traffic (e.g., a reduction in other sources of mortality or an increased reproduction rate [Roedenbeck et al. 2007]), are unlikely for wildcats because other sources of mortality for adult wildcats are generally low, and losses of young due to weather conditions and predators are generally high (Götz and Roth 2006; M. Götz, Forstzoologie, personal communication; M. Herrmann, ÖKO-LOG field research, unpublished data). We suggest that an additional source of mortality, like road mortality, is minimally a threat to small populations and a hindrance to dispersal of wildcat populations.

Road Effects on Movement Behavior

As opposed to our expectations the fenced motorway (fenced with wildcat fence) posed only a moderate barrier to wildcats. Individuals were hindered in their daily routine and some stopped crossing completely but others continued crossing regularly. This was the same for the unfenced highway (traveled by 2,500 vehicles/day). Smaller roads traveled by only a few hundred cars per day seemed to be a negligible barrier to movement but posed a mortality risk.

Fine-scale monitoring showed that wildcats were aware of roads as an obstacle. Wildcats took detours to reach hunting areas or resting places, they adapted their temporal behavior to traffic volume, and they were extremely alert when crossing at crossing structures. Wildcats moved long distances at dawn, when traffic volume was greatest but road crossings took place either 2 hours before morning peak traffic or 1–2 hours after peak traffic in the evening. Cats crossing the unfenced highway often waited for a gap in traffic flow for several minutes before crossing. Other carnivores also showed activity shifts in response to humans and behavioral responses to vehicle volume (Kitchen et al. 2000, McClennen et al. 2001, Tigas et al. 2002). Further, prior analyses indicated that wildcats generally avoided areas within 200 m of roads, but wildcats occasionally hunted or rested near roads (Klar et al. 2008). These behaviors have an energetic cost; thus, we assume that only a limited number of major roads can be tolerated within a wildcat's home range. Indeed, some individual home ranges excluded major roads. Although the barrier effect of one motorway may have a minimal effect on a wildcat population, the concurrence of several such roads may affect population persistence in the long run. In Central Europe, the

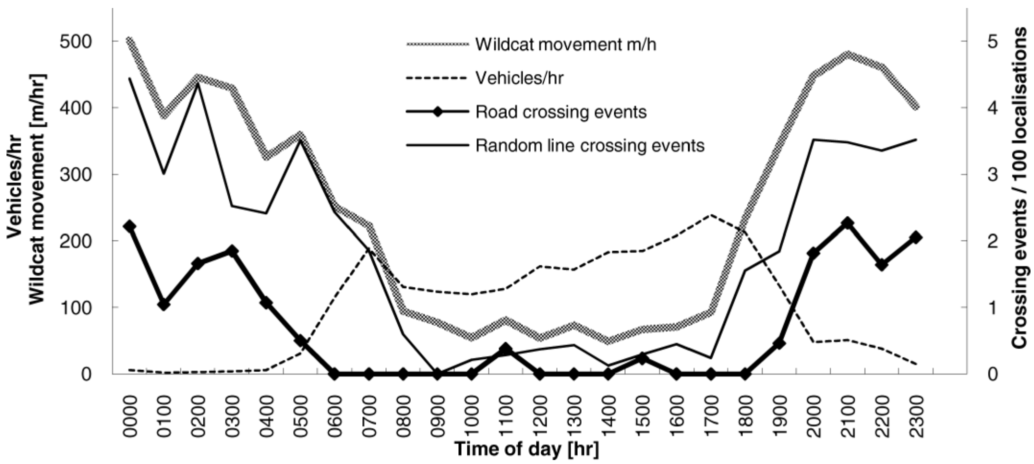

Figure 4. Hourly crossing events of roads in the study area (Rhineland-Palatinate, Germany, 2001–2005) by radiocollared wildcats compared to their average movement (m/hr), crossing events of random lines, and traffic volume (vehicles/hr). We adjusted crossing events to the number of available wildcat locations at every hour of the day. We took hourly traffic volume from the highway B50 as an example, but it has the same shape for the motorway A60 with a peak at 0700 hours and 1700 hours.

increasing network of major roads may further reduce space for medium to large mammals (Roedenbeck 2007).

The behavioral response to traffic, and that crossing frequency declined during the change from the track under construction to the motorway with traffic and fence, showed that the barrier effect was operational and not merely the result of open space caused by the roadway. Roads with a high nighttime traffic volume may be particularly problematic for the mainly nocturnal wildcats.

Use of Crossing Structures

Wildcats preferred underpasses, in particular open-span viaducts, for road crossing. Narrow overpasses for forest roads (6 m wide) were the least preferred crossing structures. Open-span viaducts were the only crossing structures where we observed no irritated behavior such as stopping, detouring, or returning. Cougars (*Puma concolor*) also prefer open-span viaducts (Beier 1995, Gloyne and Clevenger 2001). Snow-tracking showed that wildcats were guided by the fence towards viaducts. However, continuous vegetation and the linear structure of watercourses under viaducts may have had an additional guiding effect on wildcats.

As opposed to the findings of Rodríguez et al. (1997), the 2 road underpasses with low traffic (<300 vehicles/day) were used more than the 40-m-underpass and the 2 overpasses without traffic, indicating that low traffic is not a hindrance for crossing. Although wildcats appeared wary when crossing at underpasses, 2 noncollared wildcats were killed at narrow underpass number 1 in 2006, suggesting a need for safe crossing structures in combination with major barriers such as the fenced A60 motorway.

The height of the overpasses, their concrete floor, and their open view of traffic on the motorway may have deterred cats. The 40-m-wide underpass without a road was used less than expected, and cats also showed detouring and returning behavior at this underpass. Perhaps this detouring behavior was due to traffic noise or sparse vegetation cover. A preferred viaduct was only 500 m away. As with wolves (*Canis lupus*; Blanco et al. 2005), individual wildcats appeared to have a favorite crossing structure and were willing to detour >1 km to reach a preferred crossing area.

MANAGEMENT IMPLICATIONS

We recommend installing the wildcat fence at all motorways within suitable wildcat habitat where wildcats exist (Klar et al. 2008) to reduce road mortality. To minimize fragmentation, we recommend safe crossing structures (i.e., viaducts and underpasses without traffic) every 1.5–2.5 km to allow a crossing site within each home range (Bissonette and Adair 2008). Crossing structures with mortality risk, such as road underpasses, may have a negative effect on the wildcat population even though they alleviate the barrier effect of a road. Wildcats will detour >1 km by walking along the wildcat fence until a crossing structure is encountered, so we suggest terminating the wildcat fence always at crossing structures and $\geq$100 m from the forest edge (i.e., wildcat habitat). Motorway junctions or crossing roads with extensive traffic should also have a wildcat-proof fence until a crossing structure is reached.

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