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Potential Impacts of Highway Median Barriers on Wildlife: State of the Practice and Gap Analysis

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Abstract Median barriers separate lanes of traffic moving in opposite directions on multilane highways. Such traffic safety devices can reduce head-on collisions but also have the potential to reduce landscape permeability by impeding wildlife movements across highways. Median barriers may also increase the risk of wildlife–vehicle collisions if an animal becomes trapped or confused amid barriers searching for a place to cross. A 2002 Transportation Research Board report highlighted the need to better understand the potential impacts of highway median barriers on wildlife. This lack of information can cause significant project delays and increase transportation project costs. This study represents the first attempt in North America to bring together information about highway median and roadside barriers and wildlife and provide preliminary guidelines to balance the needs of motorist safety and wildlife movements.

Keywords Barrier effect · Habitat fragmentation · Highway median barrier · Motorist safety · Wildlife mortality · Landscape permeability

Introduction

Barrier or fragmentation effects of roads result when wildlife is unable to disperse across roads to locate habitats, resources, or mates (Forman et al. 2003). Behavioral avoidance of roads or limited crossing opportunities are generally attributed to road and habitat characteristics, such as traffic density, noise, and road width (Hubbard et al. 2000; Lovallo and Anderson 1996; McDonald and St Clair 2004; Lewis et al. 2011). Other physical features of roads and adjacent habitat have been shown to limit wildlife movement or to be associated with the occurrence of road-killed wildlife (Oxley et al. 1974; Cain et al. 2003; Malo et al. 2004; Ford and Fahrig 2008). Road features, including solid concrete median barriers and steel guardrails, can potentially block or limit movement of wildlife across roads (Forman et al. 2003).

Median barriers are used to separate lanes of oncoming traffic to enhance motorist safety on multilane highways. Median barriers are characterized by a variety of forms and can be classified into three groups: Rigid barriers, semi-rigid barriers, and cable barriers (Fig. 1). Many transportation agencies in North America are installing highway median barriers in the absence of information on how they affect wildlife movement and mortality, and whether median barriers may indirectly affect motorist safety. Rigid median barriers, such as concrete Jersey, have the potential to impede wildlife movements across highways given their height, mass, and linear extent on many highways. They may also increase the risk of motor vehicle accidents by causing wildlife to become trapped or confused while on the road searching for a place to cross. From a habitat fragmentation perspective, wildlife may avoid crossing roads altogether where solid concrete median barriers are in place.

Despite these potential impacts, up until now the American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide does not address the effects of highway median barriers on wildlife habitat fragmentation (AASHTO 2011). A Transportation Research Board (TRB) report highlighted the urgent need

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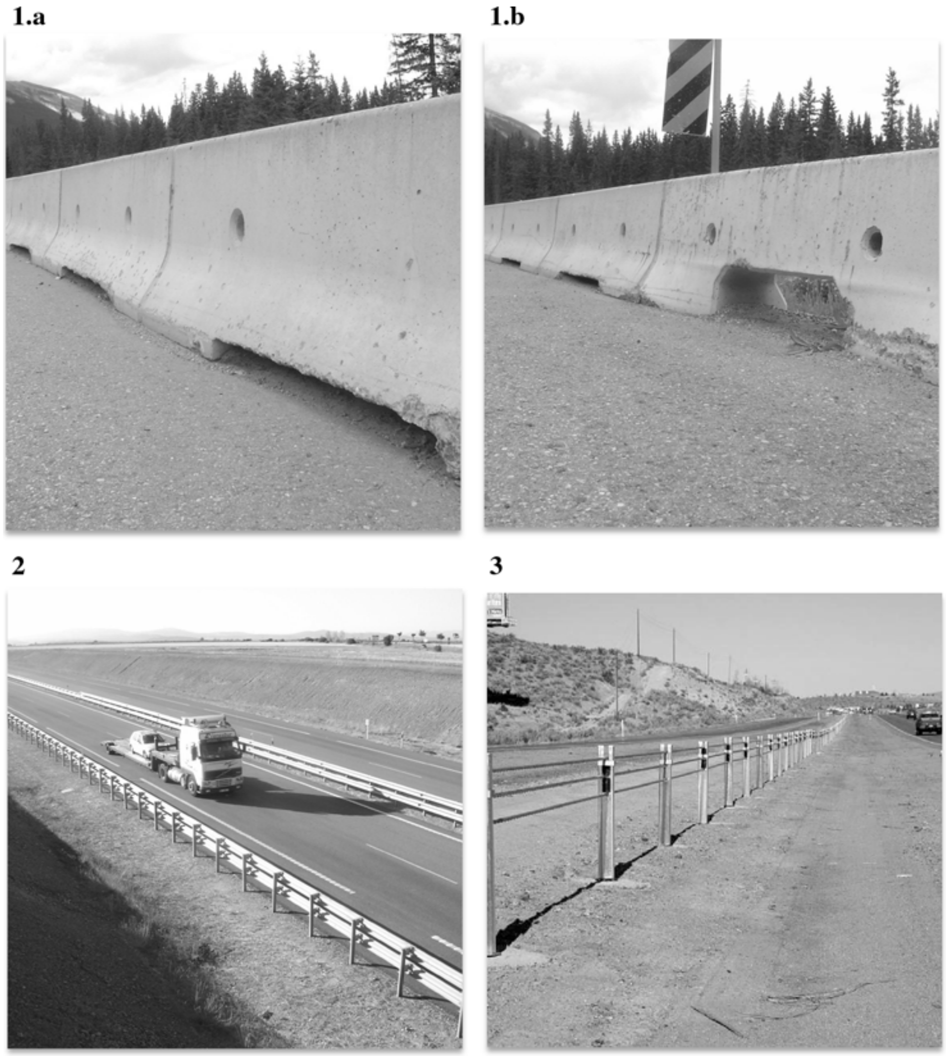

Fig. 1 Examples of three categories of commonly used median barrier designs. **1.a.** Concrete Jersey (rigid barrier). **1.b.** Concrete Jersey with scuppers. **2.** Metal beam (semi-rigid barrier). **3.** Cable barrier (flexible barrier)

to better understand how wildlife respond to and are potentially impacted by highway barriers (Transportation Research Board 2002). Land managers and transportation practitioners have identified this as a severe shortcoming that needs immediate attention.

Some median barrier designs have been used to mitigate potential barrier effects on wildlife movements. Some designs include "scuppers" or "cutouts," these consist of Jersey barriers with small passages or openings at the bases (Fig. 1). Others have gaps between Jersey barrier panels. Both designs are commonly used by transportation agencies, but they remain virtually untested (Clevenger and Kociolek 2006). The lack of information to properly assess environmental impacts can cause significant project delays and increase transportation project costs.

A state of the practice survey and gap analysis is a first step to enable transportation agencies to assess effects of median barrier projects on wildlife movements and mortality. This will help transportation agencies to meet their obligation to the public by disclosing the effects roads on wildlife, be good stewards of natural resources by mitigating those effects where warranted, and complete median barrier projects expeditiously. Results from a collective synthesis of this type produce a foundation from which to develop and initiate field studies investigating the effects and performance of a variety of median barrier designs on the movement and mortality of wildlife.

We conducted a review of the effect of median and roadside barriers (hereafter referred to as median barriers) on wildlife for the California Department of Transportation (Caltrans). Although our review and state of the practice synthesis was completed in 2006, the lack of understanding of median barrier effects on wildlife continues to be a salient issue. Further, there is continued concern by transportation and land management agencies about a lack of best management practices. To our knowledge, there has been only one additional study since 2006 [a Swedish review (Olsson 2009)] and no perceptible changes of practice within North American agencies since our report was completed (Clevenger and Kociolek 2006). The purpose of our study was to: (1) Collect, review, and synthesize literature on impacts of median barriers on wildlife, (2) survey transportation agencies to determine trends and patterns of utilization of the median barrier designs, (3) conduct a gap analysis to highlight information needs, and (4) provide preliminary guidelines for planning median barrier installation with dual needs of motorist safety and wildlife movements.

Median Barriers in Practice

Description

Median barriers are longitudinal safety devices used to separate opposing lanes of traffic on divided highways (AASHTO 2006). They are designed to enhance motorist safety by redirecting vehicles that strike either side of the barrier (AASHTO 2006). Concrete barriers are the most commonly used in urban areas while metal beam and cable barriers are common choices in rural areas (Fig. 1; Federal Highway Administration 2006a). The most commonly used concrete median barrier in the U.S. is the concrete New Jersey shape (Jersey) barrier (Ray and McGinnis 1997).

Historical Trends and Installation Guidelines

Cable median barriers have been used on U.S. highways since the 1930s (Stasburg and Crawley 2005). The first documented use of concrete median barriers dates back to the 1940–1950s in California and New Jersey when the standard was 30–46 cm (12–18 in.) tall (Kozel 1997). Years of experimentation resulted in a variety of concrete designs (Jersey, Texas, F-shape, and constant-slope) (Kozel 1997; McDevitt 2000) and the 150 cm (59 in.) Ontario Tall Wall high performance concrete barrier (Hubbs and Bonstra 1995).

By 1997, California had more than 2,600 km (1,600 miles) of concrete and metal freeway median barriers across the state (California Department of Transportation 1997). Over the past decade, the installation of median barriers by transportation agencies has become more widespread in California and other transportation agencies (Neuman et al. 2008; Olson et al. 2013). Jersey barriers, weighing 224 kg per 30 linear cm (600 pounds per linear foot), are often cast in place or slip-formed (Kozel 1997) making installation so efficient that barriers may stretch continuously for many kilometers.

Impacts to Motorists

Median head-on collisions are less frequent but can be three times as severe as other more prevalent highway crashes (Federal Highway Administration 2006a). Options to reduce opposing direction collisions include installing median barriers or widening the roadway (Persaud et al. 2004). Collectively, median barriers and similar structures have been shown to be effective countermeasures for reducing injury severity and fatalities. (Lynch 1998). In Sweden, converting wide two-lane roads to a 2 + 1 with median barrier resulted in an 80 % reduction in fatalities and 50 % reduction in severe injuries from head-on or run-off-road collisions on rural highways (Bergh and Moberg 2005).

Current Trends

The U.S. Federal Highway Administration (FHWA) accepted as crashworthy a variety of concrete, metal beam, cable, and other median barrier designs (Federal Highway Administration 2006a, b). The U.S. Department of Transportation (USDOT) has stated the need for an alternative to traditional concrete and metal beam barriers because they can be expensive and difficult to install (US Department of Transportation 2006). FHWA names cable barriers and rumble strips as two priority technologies with proven benefits and ready for deployment (Taylor 2005). Cable barriers tend to be more popular in Europe and New Zealand; however, some states and Canadian provinces are beginning to install high-tension cable barriers (Clevenger and Kociolek 2006; Johnson and Howard 2007; Olson et al. 2013).

Review of Median Barrier Effects on Wildlife

We conducted a literature review of what is known about the effects of median barriers (especially concrete designs) on wildlife mortality and movement. Appendix 1 lists the indexes, databases, and websites that were searched.

As of 1995, there were no published articles on the impacts of median barriers on wildlife (Hubbs and Boonstra 1995) although Woods (1990) briefly addressed median barriers as part of highway mitigation for elk (*Cervus elaphus*) in Alberta. Since then, few studies have attempted to evaluate the effects of median barriers on wildlife movement. There is limited knowledge on this topic and even less regarding motorist safety and wildlife collision risks due to the presence of median barriers.

Olsson (2009) conducted a review for the Swedish Ministry of Transportation and concluded that (1) cable or W-beam steel railings have lower barrier effects for wildlife than concrete median barriers; (2) where there is wildlife fencing along roads, the additional barrier effect of median cable barriers is marginal; and (3) where there is no wildlife fencing, solid median barriers may cause an increased mortality in medium-sized and large animals. He also concluded that in Sweden, cable barriers were considered a safe solution and more ecologically beneficial due to fewer carbon emissions during production compared to concrete.

Mortality

Most collisions with wildlife occur on undivided two-lane roads, while a much smaller percentage occurs near raised median barriers (Elzohairy et al. 2004; Urbitran Associates 2005). Deer (*Odocoileus* sp.) and elk road-kill locations tended to occur less often than expected in areas with a Jersey barrier in the central median (Singleton and Lehmkuhl 2000). Conversely, other researchers found collision with ungulates tended to be closer to median barriers and guardrails than expected by chance (Malo et al. 2004; Gunson et al. 2011). While the relative percentage of collisions with wildlife occurring in the presence of a raised median barrier appears low, the numbers are likely still substantial enough to constitute a motorist safety concern.

It is unclear whether a divided highway with central median barrier reduces the likelihood of collisions with wildlife. In New Jersey, 70 % ($n = 3{,}524$) of collisions with deer occurred on roads without medians or guardrails, 19 % ($n = 959$) of collisions occurred in the presence of a grassy median, while 6 % ($n = 309$) occurred in the presence of a concrete barrier (Urbitran Associates 2005). This study, however, failed to report what the proportion of road was occupied by each median type. A model of deer–vehicle collisions also illustrated that highways with grassy medians were associated with higher mortality rates than those with median barriers, but those with Jersey barriers were associated with higher collision rates than undivided two-lane highways (Meyer and Ahmed 2004).

On an unfenced, 4-lane highway in Alberta, collisions with elk were not explained by concrete or grassy medians (Woods 1990). A road-kill study of small terrestrial vertebrates in the same area found that the number of median barriers along roadways was not a factor in explaining road-kill occurrence of small- and medium-sized vertebrates (birds, mammals, amphibians), but birds were 85 % more likely to be killed on roads with vegetated medians than on roads without medians (Clevenger et al. 2003).

Anecdotal evidence gathered in an expert-opinion rapid assessment made a potential link in several road-killed wildlife species with the presence of concrete median barriers (Lloyd and Casey 2005). Road-kill rates of small- to medium-sized mammals were not higher or significantly different in road sections with concrete median barriers compared to those without concrete median barriers (Armstrong 1994 in Hubbs and Boonstra 1995). An independent unpublished report on a connectivity study on Highway 401 in Ontario suggests that the presence of a continuous concrete median barrier (including the Ontario Tall Wall) tends to increase the incidence of mammalian road-kill (Ross 2004).

Much of the data reviewed suggests that raised median barriers may not be correlated with higher than average road-kill rates, however, barriers appear to partially explain how, and if, different species of wildlife move along or across roadways. The variable results may be explained by confounding factors that may not have been included in the analysis, e.g., effects of habitat quality, local animal abundance, and topographical constraints.

Movement

All types of roadway barriers can potentially limit wildlife movement and access to critical resources. Continuous, solid designs, such as concrete median barriers, are presumed to have a greater impact. These may prevent wildlife from traversing over or under the structure, increase the time it takes to traverse the barrier, or modify the behavior of the wildlife. In contrast to other median barrier types, concrete median barriers are generally least passable to most wildlife (Hubbs and Boonstra 1995).

Species-specific biology, behavior, size, and physical ability likely affect whether or not a particular wildlife would attempt to traverse or be repelled by a concrete Jersey or similar raised barrier. There are anecdotal observations of wildlife milling, or being perceived as "trapped," on roadways with a concrete Jersey barrier as well as sightings of deer moving across the highway in the presence of a Jersey barrier (Lloyd and Casey 2005). In an experimental study with captive desert tortoises (*Gopherus agassizii*) solid roadside barriers blocked movements, causing them to travel parallel for several minutes then stop or travel away from the highway (Ruby et al. 1994).

Highway dividers, such as guardrails and concrete barriers with gaps for wildlife passage, did not appear to block deer movement across highways or influence where deer chose to cross (Hostick and Styskel 2005). One explanation was that deer did not notice the gaps designed for passage (Hostick and Styskel 2005). A Western gray squirrel (*Sciurus griseus*) population decreased after concrete median barriers were installed (Hostick and Styskel 2005); however, it is unclear whether the decline was attributed at least in part to other factors.

In some cases, roadside barriers such as guardrails may have the same effects as median barriers. Track counts of mammals along highways in Colorado indicated that crossing zones of most mammals were negatively correlated with highway sections with barriers such as Jersey barriers, guardrails, walls, or cliffs (Barnum 2003). Barriers were avoided when entering a roadway, rarely walked in the narrow space between the barrier and road surface and tended to jump over Jersey barriers and guardrails to exit a roadway (Barnum 2003). On Interstate 90 in Washington State, where Jersey barriers were located in the median and variably on one or both shoulders, the absence of ungulate road-kills suggested that the highway was a formidable barrier to their movement (Singleton and Lehmkuhl 2000).

Wildlife can travel long distances along roads without barriers before crossing (Carbaugh et al. 1975; Barnum 2003). On roadways with barriers wildlife crossing zones are generally situated at gaps between and at ends of barriers (Barnum 2003; Gunson et al. 2011). This effect, if left unchecked, can funnel wildlife onto the roadway and can concentrate wildlife–vehicle collisions (Barnum 2003). In road segments requiring barriers, Jersey barriers and guardrails could serve a double function for safety and for guiding wildlife to crossing structures (Barnum 2003; Singleton and Lehmkuhl 2000). To our knowledge, the effects of cable and other forms of median barriers on wildlife movement and/or mortality have not been explored.

Mitigation

Alternatives to solid concrete median barriers are being used to mitigate the potential barrier effect; these include cable barriers, thrie-beam, rumble strips, Jersey barrier cut-outs or scuppers, and spaced concrete median barriers (Hubbs and Boonstra 1995; Clevenger and Kociolek 2006). Many of these techniques remain untested with regard to wildlife movements.

A variety of median safety practices have been recommended and might benefit both motorists and wildlife (Bank et al. 2002). These include (1) creating wider separation between lanes of traffic without barriers, thus allowing wildlife to cross at-grade, i.e., at road level; (2) installing barrier types that prevent vehicle cross-over, but allow at-grade wildlife movement; (3) providing gaps between barriers to allow at-grade crossings; (4) installing solid barrier in combination with wildlife fencing and crossing structures; and (5) utilizing solid median barriers along the roadside to funnel wildlife to crossing structures (Clevenger and Kociolek 2006; Olsson 2009).

Wider medians cause an additional loss of natural habitat but may have less ecological impact than a narrow, paved median with a barrier, or guardrail (National Research Council 2005). It is generally accepted that wider medians have lower collision rates (Gabler et al. 2005; Knuiman et al. 1993 in Gattis et al. 2004; Strathman et al. 2001). Highway mitigation designed for dispersing wolves included a wide separation between lanes, but there was no evidence that it facilitated wolf crossings (Kohn et al. 2000).

A FHWA-approved cable barrier design was used in a median barrier installation project in Utah, primarily to mitigate potential wildlife impacts (Federal Highway Administration 2006c). Cable barriers were chosen because they were believed to allow wildlife movement, meet safety requirements, have less of a visual impact, and were less expensive to install and maintain. In response to concerns raised during an environmental assessment, the Ontario Ministry of Transportation proposed to install two 100 m [328 ft] segments of a modified thrie-beam type barrier for wildlife passage in place of a continuous Ontario Tall Wall concrete barrier (Ross 2004).

Some transportation agencies install Jersey barriers with a modified design that allows passage of small- to medium-sized mammals. In a known hotspot for collisions on California SR 52, Caltrans installed concrete median barriers with 1-m-wide gaps for deer, gray foxes (*Urocyon cinereoargenteus*), coyotes (*Canis latrans*), and small mammals (Federal Highway Administration 2006c). A median barrier project on Highway 1 near San Luis Obispo, California, was noted for environmental excellence for a context-sensitive solution by including semi-circular openings at-grade to allow small- and medium-sized wildlife crossings (AASHTO 2005).

Oregon Department of Transportation (ODOT) installed 81 cm (32 in.) tall concrete median barriers with an arched cutout or scupper (15 cm [6 in.] diameter) in the bottom center of each 3.5 m (11.5 ft) block allowing for small animal passage and drainage of surface water. In addition, every 30–152 m (100 or 500 ft) ODOT inserted 51 cm [20 in.] gaps for animal movement and roadway maintenance concerns (Hostick and Styskel 2005). Cooper (1999) recommended scuppers for the passage of smaller wildlife measuring 25 cm [~9 in.] high and 100 cm [~39 in.] wide cut-outs along the bottom, accounting for at least 20 % of the barriers or one every 5th barrier (Cooper 1999). Upgrades of the Trans-Canada Highway in Banff National Park, Alberta, included concrete median barriers with scuppers for small fauna (McGuire and Morrall 2000) and placed them only on sections where habitat connectivity was believed to be important. There is no information regarding how well scuppers perform and there are no standard guidelines regarding their placement (National Research Council 2005). However, a Washington State Department of Transportation (WashDOT) Design Manual does address the impacts of concrete median and roadside barriers on wildlife and provides a flow chart to help determine the effect of barrier placement (Washington State Department of Transportation 2005).

Evaluation of Potential Wildlife Impacts

For the purpose of determining the effect of median barriers on wildlife movements and potential risks to motorists, dimensions such as height, width, and length, all that influence permeability, are important variables. While it is recognized that certain areas are more likely to sustain wildlife populations and constitute wildlife crossing zones than others, the following matrix analysis was conducted with the assumption that at some point in time, each of these species might encounter one of these types when attempting to cross roads. In keeping with the main median barrier design types addressed above, the following median barrier types were used in a qualitative evaluation of potential permeability and potential mortality risk to wildlife.

- Concrete (Jersey, F-shape, Texas constant-slope, etc.).
- Concrete Ontario tall wall.
- Concrete with gaps.
- Concrete with scuppers.
- Concrete with gaps and scuppers.
- Metal beam (steel, W, box, thrie, etc.).
- Cable (3-, 4-strand, and proprietary designs).
- Centerline rumble strips.
- Vegetated median (center strips of grass, shrubs, or trees).

We classified North American taxonomic groups by general body size differentiation into five taxonomic groups:

(1) Mice, shrews, frogs, salamanders, lizards, and snakes.
(2) Rat families, squirrels, weasels (*Mustela* sp.), turtles, young waterfowl, and upland birds.
(3) American marten (*Martes americana*), fisher (*M. pennanti*), mink (*Mustela vison*), badger (*Taxidea taxus*), skunk (*Mephitis* and *Spilogale* sp.), fox (*Vulpes* and *Urocyon* sp.), and opossum (*Didelphis virginiana*).
(4) Coyote, bobcat, lynx, wolverine (*Gulo gulo*), otter (*Lontra canadensis*), raccoon (*Procyon lotor*), and ocelot (*Leopardus pardalis*).
(5) Grizzly bear (*Ursus arctos*), black bear (*U. americanus*), wolf (*Canis lupus*), moose (*Alces alces*), elk, deer, bighorn sheep, and mountain lion (*Puma concolor*).

Potential Permeability

Potential permeability scores were qualitatively assigned based on the physical size and ability of each taxonomic group to traverse each barrier type, independent of potential traffic mortality risk. Potential permeability was viewed in absolute terms—whether wildlife could traverse, climb over or crawl under a barrier given enough time, i.e., if the barrier was on a road with no cars. This qualitative analysis is not intended to be a guideline but rather a starting point for discussion within agencies and designing research to evaluate median barriers and wildlife movement.

Concrete barriers (solid and continuous) range in permeability from no or low to high depending on the taxonomic group. However, even solid concrete barriers often have nominal notches at the base for installation purposes that may serve the smallest wildlife. The Ontario Tall Wall at almost 1.5 m (5 ft) tall likely allows no or low permeability for all taxonomic groups. Concrete with gaps, concrete with scuppers, and concrete with gaps and scuppers maintain permeability for mid- to large-bodied wildlife of taxonomic groups 4 and 5, but less for smaller animals depending on the spacing of the gaps, scuppers, and dimensions of the scuppers. Depending on the size of the scuppers, mid-sized wildlife of taxonomic group 3 may or may not be able to utilize them. The permeability of metal beam, cable, centerline rumble strips, and vegetated median are rated high for all taxonomic groups (Table 1).

Potential Mortality

Potential mortality risk was assessed in terms of the extent to which a barrier might limit or impede an animal's ability to clear the barrier and avoid an imminent collision with an oncoming vehicle and to see approaching vehicles on the other side of the median. The score also took into consideration literature references that indicated a higher risk of wildlife–vehicle collision (especially deer) on undivided two-lane roads and on roads with grassy and vegetated medians.

Concrete barriers (solid and continuous) pose the greatest threat to the small- to mid-sized animals in the taxonomic 1–3 groupings. Larger animals have an advantage of being able to climb or jump over the barrier while seeing approaching vehicles on the other side of the median; however, the mere presence of the barrier likely hinders the speed at which the animal can cross the road while avoiding collision. The Ontario Tall Wall likely poses a high mortality risk to all species.

Concrete median barriers with gaps may enhance crossing opportunities for taxonomic groups 1–3, but gaps also may create new collision hot spots for some species in taxonomic groups 4 and 5. Concrete with scuppers has a similar score with the exception of mid-sized animals of taxonomic group 3 that may not easily and quickly pass through a scupper in time to avoid a collision. Concrete with gaps and scuppers likely enhances safe crossing opportunities for small- to mid-sized animals compared to solid concrete barriers but remains equally likely to pose a moderate mortality risk to all species. Metal beam, cable, centerline rumble strips, and

Table 1 Potential permeability of median barriers for taxa groupings of different sizes

	Taxonomic group				
Median Barrier Type	1	2	3	4	5
Concrete	1	1	2	3	3
Ontario Tall Wall	1	1	1	1	1
Concrete with gaps	2	2	2	3	3
Concrete with scuppers	2	2	2	3	3
Concrete with gaps and scuppers	2	2	2	3	3
Metal beam	3	3	3	3	3
Cable	3	3	3	3	3
Centerline rumble strips	3	3	3	3	3
Vegetated median	3	3	3	3	3

No to low permeability	1
Moderate permeability	2
High permeability	3

Red, yellow, and green were assigned to indicate no to low permeability, moderate permeability, or high permeability, respectively. Taxonomic groups, ranging from small to large bodied animals, are described in "Evaluation of Potential Wildlife Impacts" section

Table 2 Potential mortality risk of median barriers for taxa of different sizes

	Taxonomic group				
Median Barrier Type	1	2	3	4	5
Concrete	1	1	1	2	2
Ontario Tall Wall	1	1	1	1	1
Concrete with gaps	2	2	2	1	1
Concrete with scuppers	2	2	1	2	2
Concrete with gaps and scuppers	2	2	2	1	1
Metal beam	3	3	3	2	2
Cable	3	3	3	2	2
Centerline rumble strips	3	3	3	2	2
Vegetated median	3	3	3	2	2

High mortality risk	1
Moderate mortality risk	2
No to low mortality risk	3

Note that color codes are reversed from the matrix above: red signifies high mortality risk, yellow signifies moderate mortality risk, and green signifies no to low mortality risk. Taxonomic groups, ranging from small to large bodied animals, are described in "Evaluation of Potential Wildlife Impacts" section

vegetated median have essentially the same associated mortality risk for animals of taxonomic group 3 and smaller. Given the similar height of metal beam and cable barrier to standard concrete designs, the risk for larger animals (taxonomic groups 4 and 5) remains unchanged. Based on the literature sources, undivided two-lane roads (and likely those with centerline rumble strips) and roads with certain types of vegetated medians can pose a moderate mortality risk to animals in taxonomic groups 4 and 5 (Table 2).

Total Potential Risk

Scores based on potential permeability and mortality risk were summed for a total potential risk score (Table 3). Based on this matrix model, small- to mid-sized animals (taxonomic groups 1, 2, and 3) have the greatest range in risk: High with solid, continuous concrete designs; moderate with mitigated concrete designs; low with roads that utilize permeable barrier designs or no raised median barrier at all. Larger-bodied animals (taxonomic groups 4 and

Table 3 Combined risk score based on potential permeability and mortality risk of median barrier type for taxa of different sizes

	Taxonomic group				
Median Barrier Type	1	2	3	4	5
Concrete	2	2	3	5	5
Ontario Tall Wall	2	2	2	2	2
Concrete with gaps	4	4	4	4	4
Concrete with scuppers	4	4	3	5	5
Concrete with gaps and scuppers	4	4	4	4	4
Metal beam	6	6	6	5	5
Cable	6	6	6	5	5
Centerline rumble strips	6	6	6	5	5
Vegetated median	6	6	6	5	5

High combined risk score	2 or 3
Moderate combined risk score	4 or 5
Low combined risk score	6

Taxonomic groups, ranging from small to large bodied animals, are described in "Evaluation of Potential Wildlife Impacts" section

5) have a moderate risk for all types of median designs with the exception of Ontario Tall Wall, which is likely to have a high risk because of its height.

State of the Practices Survey

The Transportation Research Board has stated the need to better understand the potential impacts of highway barriers (Transportation Research Board 2002). The majority of the literature addressing median barriers focuses on motorist safety (Ray et al. 2003). The goal of our survey was to obtain the most up-to-date information on the current practices and knowledge of transportation agencies in planning projects with highway median barriers. Our state of the practice survey and literature review was the first that we are aware of that specifically addresses the potential effect of median barriers on wildlife in North America.

As mentioned above, the survey was conducted in 2006 for the California Department of Transportation (Caltrans). We include the results of this survey because since the time of the report, median barriers and wildlife have continued to be an important concern among North American transportation agencies and there has been little with regards to understanding their effect on wildlife or how best mitigate their effect through use of different designs.

Survey Participation

Ninety-six-targeted biological/environmental and engineering specialists in transportation agencies in the U.S. and Canada were invited to participate in the online survey. The survey was made available via http://questionpro.com. Targeted specialists were invited to participate on April 12, 2006. The survey remained active until July 30, 2006 to ensure the highest rate of participation possible.

Thirty-four individuals representing 28 transportation agencies completed the survey. Twenty of the participants were engineering specialists (including design, traffic, safety and maintenance) and 14 were biologists or environmental specialists (including natural resources and land management). The resulting overall agency response rate was 45 % (29 of 64 transportation agencies).

Nine other agencies (8 states and 1 province) responded but did not participate because they lacked the design, technical, or historical knowledge required. The interdisciplinary nature (biology and engineering) of this survey was cited as a challenge because agency personnel are often separated by focus area and associated job tasks.

Survey Questions and Results

One questionnaire was developed for both engineering and environmental specialists. Questions focused on utilization history, trends, performance evaluation of various median barrier designs, studies of median barrier effects on wildlife and motorist safety, mitigations for wildlife, and implications for transportation planning. Survey questions as they appeared online are shown in Appendix 2.

Survey Summary

Agency personnel that took the survey were near equally balanced between environmental (14) and engineering (20) backgrounds. Most participants seemed better versed in the cross-over safety aspect of median barriers than the wildlife impacts. It was evident that there is little interdisciplinary overlap between biologists and engineers who often were unable to answer cross-discipline questions. In many cases, multiple follow-up responses from as many as three staff from one agency were combined with the comments of those who actually participated in the survey.

Most participating agencies (84 %) indicated they rely on AASHTO's Roadside Design Guide either singly or in combination with other guidelines. Concrete Jersey and metal beam barriers were the most commonly used median barriers used in urban and suburban areas and the trend remains stable. The historical onset for using cable median barriers has been more variable among agencies, but current and projected installations are increasing among transportation agencies. Centerline rumble strip installations also appear to be increasing.

Several respondents knew about the importance of wildlife crossings and addressing median barriers, but few could comment on the potential impacts of median barriers or their mitigation. One state (Oregon) studied the impacts of median barriers on deer (Hostick and Styskel 2005). The most common and highest ranked reason agencies chose to not conduct wildlife/median barrier studies were "No perceived need to conduct such research" followed by "No mandate to conduct such research." However, when asked which species or groups may be affected, the collective agency-generated list included a broad range of species and taxonomic groups including herptiles (reptiles and amphibians), birds, and all mammal species. Nearly all agencies indicated they rarely employ (77 %) or consider (68 %) mitigative median barrier designs. The full survey results can be found in Clevenger and Kociolek (2006).

Synthesis of Literature Review and Survey

The survey demonstrated there is a wealth of information about different median barrier designs, their cost–benefits, and collision reduction potential. In contrast, there is a glaring lack of information about how the ubiquitous median barriers on our highways may impact wildlife. The dearth of information is consistent throughout the taxonomic ranks, from small herptiles to wide-ranging and fragmentation–sensitive species.

There was an equally obvious knowledge gap about any real or perceived risks of vehicle collisions with wildlife as a result of median barriers on highway. This scarcity of information coincides with a general lack of empirical information regarding different median barrier designs in varying landscapes and their influence on wildlife movements and habitat connectivity. As a result, even the most basic or cursory guidelines to help transportation agencies when working on median barrier projects do not exist. A concerted effort to research the interactions between vehicles, median barriers, and wildlife will serve to narrow the wide information gap and structure a foundation from which to begin setting agency standards and best management practices.

Knowledge Base

Our review and survey highlighted what knowledge has been acquired about median barriers and wildlife, and underscore where conspicuous information gaps lie. The knowledge base can be summarized in six points.

(1) *Median barriers likely have an effect on movements of a wide range of wildlife from small to large* There was agreement within the literature and among survey respondents that barriers result decreased wildlife movements and can partially explain increased wildlife mortality. Few studies have addressed this issue and future studies should attempt to confirm the effect and how it may vary among species and different landscapes.

(2) *Raised concrete median barriers continue to be installed on highways today* Their continued use should be of concern in areas where they bisect areas of ecological importance and wildlife populations of conservation concern.

(3) *There is an increasing use of cable barriers and rumble strips* These are proven measures to increase motorist safety, are less costly than other median barrier applications, and intuitively allow greater wildlife movement compared to solid median barrier designs.

(4) *Mitigative design solutions for median barriers are rarely used by transportation agencies* Lacking a clear mandate to address wildlife and habitat connectivity concerns, in few cases agencies employ mitigative designs and rarely even consider them.

(5) *There is a need for more study* The literature review and survey demonstrated the urgent need for more research, as respondents had conflicting opinions of cost–benefits, impacts to wildlife, and performance of mitigative design solutions. Future research should focus on the three ways median barriers can impact wildlife: mortality, reduced movements, and population viability. Study designs could use a multivariate analysis using an information-theoretic approach or for more inferential strength use a before–after-control-impact (BACI) approach (Roedenbeck et al. 2007; Zuur et al. 2007).

Planning Implications

Before any specific and conclusive implementation recommendations can be adopted, further field-based research is required. The primary implementation recommendation is to conduct rigorous research to test the effects of different median barrier types and associated mitigative strategies on a variety of taxa. In the interim, however, based on synthesis and survey, we propose eight guidelines to help transportation agencies in planning median barrier installation with dual needs of motorist safety and wildlife movements.

(1) Mitigative designs for raised highway median barriers should be used where highway barriers bisect natural or semi-natural areas and wildlife populations of conservation concern.
(2) The Ontario Tall Wall or Texas Jersey barrier should not be installed in areas that bisect critical wildlife habitats and populations, particularly where habitat connectivity for large mammals is of conservation interest.
(3) In areas where mitigative designs consisting of concrete, metal, or cable barriers are considered, the more permeable metal or cable designs should be installed for the benefit of primarily small- to mid-sized taxa, and secondarily large wildlife species.
(4) In areas where continuous concrete designs are warranted, scuppers (basal cut-outs) should be used and spaced at intervals that correspond to the movement requirements of focal taxa or the least mobile species in area, thus meeting the passage and connectivity needs of focal taxa.
(5) In areas where raised median barriers are warranted, funnel animals toward below-grade (below road level) passages including wildlife underpasses, bridges or culverts over creeks, and rivers.
(6) In areas where centerline rumble strips are an option on undivided two-lane roads, consider their use to improve motorist attentiveness, reduce risk of collisions with wildlife, and increase permeability of roads to wildlife movements.
(7) In areas with vegetated medians, minimize shrubbery that has been shown to attract wildlife and increase vehicle-caused mortality.
(8) Monitor the performance of median barriers and mitigative designs in meeting the dual needs of increasing motorist safety and highway permeability for wildlife. Research should be designed to provide strong inferences regarding effects and sound recommendations for future planning and installation of median barriers (Roedenbeck et al. 2007).

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Appendix 1: Indexes, Databases, and Websites Searched for Literature Review

Western Transportation Institute's in-house ProCite Database.
Biological Abstracts.
Dissertation Abstracts.
Ecology Abstracts.
TRIS Online.
FHWA Critter Crossings.
Wildlife Crossings Toolkit.
Wildlife and Ecology Studies Worldwide.
Applied Science & Technology Abstracts.
InfoTrac OneFile (multidisciplinary index).
Academic Search Premier (multidisciplinary index).
Compendex.
Web of Science.
Government Publications.
International Conference on Ecology and Transportation (ICOET proceedings).
FHWA Environmental Research Database.
Wildlife, Fisheries and Transportation Research.
Road Ecology Center at UC-Davis.
Infra Eco Network Europe.
Deercrash.com.
Google Scholar.
Google.

Appendix 2: Median Barrier State of the Practice Survey

I. Background information

a. Last name.
b. First name.
c. State/Province.
d. Agency.
e. Position title.
f. Area in your charge (i.e., state/province, region, district, etc.).
g. Number of years in the transportation field.

h. Responsibilities (brief).
i. Email.
j. Phone number.

II. Survey questions

Utilization history

1. What types of median barriers does your agency use on any or all roadway types, i.e., multi-lane interstate, two-lane rural roads, etc.? Please select all that apply.

   a. Concrete Jersey or NJ-shape.
   b. Concrete F-shape.
   c. Concrete constant-slope Texas.
   d. Concrete low profile.
   e. Steel beam.
   f. Thrie-beam.
   g. Cable (Safence).
   h. Cable (three-strand).
   i. Cable (four-strand).
   j. Centerline rumble strips.
   k. Grassy strip.
   l. Painted centerline.
   m. Other (please describe).

2. When did your agency…[select: (i) Last year, (ii) 5 years ago, (iii) 10 years ago, (iv) 15 years ago, (v) 20 or more years ago, (vi) not applicable].

   a. Begin installing raised median barriers of any type?
   b. Begin installing concrete Jersey or F-shape median barriers?
   c. Discontinue installing concrete Jersey or F-shape median barriers?
   d. Begin installing concrete constant-slope Texas median barriers?
   e. Discontinue installing concrete constant-slope Texas median barriers?
   f. Begin installing steel or thrie-beam median barriers?
   g. Discontinue installing steel or thrie-beam median barriers?
   h. Begin installing cable median barriers?
   i. Discontinue installing cable median barriers?
   j. Begin installing centerline rumble strips?
   k. Discontinue installing centerline rumble strips?
   l. Begin installing grassy median barriers?
   m. Discontinue installing grassy median barriers?

3. What criteria/variables does your agency use/analyze to determine the need for median barrier installation? Please select all that apply.

   a. Historical cross-over collision records.
   b. Cost–benefit analyses.
   c. Collision probability models.
   d. Average daily traffic.
   e. Median width.
   f. Posted speed limit.
   g. Roadway segment in relation to interchanges or other roadway feature.
   h. Controlled access.
   i. Slope.
   j. Environmental factors.
   k. Geometric factors.
   l. Traffic factors.
   m. Rural/suburban/urban location.
   n. Other (please describe).

4. What guidelines does your agency use to determine the type and location of median barrier installations? Please select all that apply.

   a. AASHTO (American Association of State Highway and Transportation Officials) Roadside Design Guide
   b. State/Provincial guidelines.
   c. Agency guidelines.
   d. Another state/province agency's guidelines.
   e. Use ad hoc approach.
   f. Not applicable; no need for median barrier installation guidelines.

5. Please describe any specific uses for barrier types utilized by your agency, i.e., as median barrier versus edge barrier, in high snow areas versus snow-free areas, etc.

Trends

1. Please characterize your agency/state/province's installation trends for each of the following median barrier types [select: (i) increasing, (ii) stable, (iii) decreasing, (iv) not applicable].

   a. Concrete Jersey or F-slope,
   b. Concrete constant-slope Texas,
   c. Steel or thrie-beam,
   d. Cable,
   e. Centerline rumble strips,
   f. Grassy median,
   g. Please describe any other trends in the use of median barriers by your agency/state/province.

2. Please select the median barrier type your agency is most likely to use for each of the following roadway types [select: (i) Concrete Jersey/F-slope, (ii) concrete constant-slope Texas, (iii) steel/thrie-beam, (iv) cable, (v) centerline rumble strips, (vi) grassy median, (vii) painted centerline].

   a. Rural 2-lane,
   b. Rural 4-lane,
   c. Suburban 2-lane,

d. Suburban 4-lane,
e. Suburban >4-lane,
f. Urban 2-lane,
g. Urban 4-lane,
h. Urban >4-lane,

Performance evaluation

1. Has your agency studied the effectiveness of installed median barriers for motorist safety?

   a. Yes.
   b. No.
   c. I do not know.

If yes, what type of median barrier(s) was studied?

If yes, what were the measures of effectiveness? Please select all that apply.

a. Reduction of cross-over collisions.
b. Reduction of cross-over collision fatalities.
c. Reduction of injury severity.
d. Lives saved.
e. Dollars saved.
f. Other (please describe).

2. Did the installation of median barriers enable your agency to achieve its a priori goal(s) for increasing motorist safety?

   a. Yes.
   b. No.
   c. I do not know.

3. Has your agency studied the effects of median barriers on wildlife movement and/or mortality?

   a. Yes.
   b. No.
   c. I do not know.

If yes, please explain general findings and provide report citations.

If no, is any such research being considered or planned for the future?

a. Yes.
b. No.
c. I do not know.

If yes, please briefly explain scope/type of planned study, projected date, stage of project, targeted species, etc.

If no, please rank your agency's reasons for not studying the effects of median barriers on wildlife movement and/or mortality (1 = Highest, 5 = Lowest).

a. Too expensive.
b. Too time consuming.
c. No specialized personnel to conduct study.
d. No mandate to conduct such research (no species which are endangered, threatened or of special concern).
e. No perceived need to conduct such research.
f. If there are other reasons not listed above, please describe.

4. Have any unforeseen negative impacts resulted from different types of median barrier installations by your agency/state/province? Please select all that apply. [select: (i) Concrete Jersey/F-slope, (ii) concrete constant-slope Texas, (iii) steel/thrie-beam, (iv) cable, (v) centerline rumble strips, (vi) grassy median].

   a. Increased in fixed object (median barrier) collisions.
   b. Increase in re-directional collisions.
   c. Increase in motorist fatalities.
   d. Increase in motorist injuries.
   e. Increase in motorist injury severity.
   f. Increase in general maintenance costs.
   g. Increase in weather-related maintenance costs or challenges.
   h. Decrease in emergency service and/or law enforcement accessibility.
   i. Increase in wildlife mortality.
   j. Decrease in wildlife mobility across the roadway.

Mitigation for wildlife

1. What species (deer, bears, etc.) or groupings (small mammals, reptiles/amphibians, etc.) of wildlife appear to be most affected by roadways with raised median barriers in your jurisdiction?
2. How frequently does your agency/state/province *consider* mitigative design solutions to median barrier impacts on wildlife movement and/or mortality? (e.g., spacing of barriers, scuppers, passages, etc.).

   a. Always,
   b. Usually,
   c. Sometimes,
   d. Rarely,
   e. Never,
   f. Not applicable.

3. How frequently does your agency/state/province *employ* mitigative design solutions to median barrier impacts on wildlife movement and/or mortality?

   a. Always,
   b. Usually,
   c. Sometimes,
   d. Rarely,
   e. Never,
   f. Not applicable.

Implications for transportation planning

1. Has your agency encountered any practical or regulatory issues regarding the use of median barriers in your state/province?

    a. Yes.
    b. No.
    c. I do not know.

2. Does your agency know of any practical or regulatory issues regarding the use of median barriers across states/provinces/the country?

    a. Yes.
    b. No.
    c. I do not know.

If yes, are these issues related to: (a) Motorist safety? (b) Wildlife movement and/or mortality?

a. Yes.
b. No.
c. I do not know.

Please explain.

3. Is your agency planning any changes in its approach to using median barriers? (e.g., type of barrier, placement, etc.).
4. What suggestions or comments do you have regarding median barriers, motorist safety and wildlife movement and/or mortality that might not have been addressed in this survey?
5. If you would like to receive a report of the survey results, please check here.

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