Highway Crossings for Herptiles (Reptiles and Amphibians)

Requested by
Margaret Gabil, Caltrans District 4, Division of Environmental Planning & Engineering

November 2, 2012

The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

Caltrans wishes to understand best and most current practices for protecting reptiles and amphibians (collectively, "herptiles," "herps" or "herpetofauna") at highway crossings. This Preliminary Investigation sought to provide information that Caltrans practitioners could use to more effectively implement herptile highway crossings and reduce mortality among regulated species.

This Preliminary Investigation addresses central questions on this topic: What are the critical issues in terms of best practices for designing and placing herptile crossings? How effectively are they working (and how is efficacy measured)? What are the cost issues? How do California's unique species and ecosystems play a role?

As a starting point Caltrans provided an extensive annotated review of literature on this topic (see Appendix A), which includes more than 80 citations dating from 1982 to 2012.

Summary of Findings

There is an abundance of literature and information on this topic, as suggested by the lengthy appendix provided by Caltrans. We focused our information collection efforts in two areas: **Expert Interviews** and **Resources**.

Expert Interviews

We spoke with or corresponded with several researchers and practitioners. These discussions revealed three new books on this topic, all to be published in the coming months. High-level highlights from these interviews follow.

We spoke with four **Researchers** in this area: one in Florida, two in Canada and one in the United Kingdom.

- Ken Dodd, University of Florida, discussed details of the Paynes Prairie ecopassage in Florida and its effectiveness in protecting herptiles. He also provided information from his forthcoming book on this topic.
- Lenore Fahrig, Carleton University (Ottawa, Canada), talked about the effectiveness of existing herptile crossings and addressed the conflicting issues of mortality versus connectivity. (What is the relative concern of preventing animals from dying on roads compared with preventing population fragmentation?) According to Fahrig, keeping animals off the roads is a higher priority than connecting populations, particularly with threatened or endangered species.
- David Lesbarrères, Laurentian University (Sudbury, Canada), emphasized the impact that variation in herptile behavior, from species to species and even within species located in different environments, has on crossing design. Lesbarrères also addressed the mortality versus connectivity issue, talked about approaches for designing crossings for new roads compared with retrofit projects and provided information about a forthcoming Australian publication he is co-authoring with Tom Langton. (See next bullet.)
- Tom Langton, Herpetofauna Consultants International (Suffolk, United Kingdom), stressed the need for more research-based guidance and talked about research and information sharing he has conducted in California. He also provided German federal guidelines for amphibian crossings.

Among **State DOTs**, we reached three individuals in nearby states: Arizona, Nevada and Washington State. We also spoke with representatives from three other states with experience in this area: Florida, Indiana and New York State.

- Julie Ervin-Holoubek, Nevada DOT, described the state's efforts to connect its desert tortoise population. She talked about placement, design and costs.
- Paul Wagner, Washington State DOT, discussed crossings in the state and mentioned the importance of thinking about "connecting habitats more than the mechanics of individual species."
- Tom Kombe, Arizona DOT, put us in touch with the researcher for an Arizona study on the desert tortoise. (See the interview with David Grandmaison on page 18 of this report.)
- Vicki Sharpe, Florida DOT, discussed at length the herptile crossings implemented in Florida. She shared Florida's high-level guidance and noted a number of resources that she finds valuable. She also provided names of additional experts that might be of interest to Caltrans.
- Debra Nelson, New York State DOT, offered to hold a conference call with Caltrans and the key stakeholders in recent herptile crossing research in the state.
- David Glista, Indiana DOT, discussed his own research in this area. He offered to provide further information to Caltrans based on project-specific questions that the agency might have.

In **Other Government Agencies** we include information gained from a California-based representative of the U.S. Department of Agriculture (USDA) Forest Service, a California-based U.S. Geological Survey (USGS) representative and an Arizona Game and Fish Department researcher.

- Sandra Jacobson, USDA Forest Service, is an expert in road ecology and provided extensive input regarding considerations for herptiles. Her comments reflect a short course she teaches on this topic. Jacobson addressed such considerations as reproductive potential, antipredator adaptations, limitations on the usefulness of roadkill data, crossing suitability, the effectiveness of combining crossings and barriers, and types of animal movement. Jacobson discussed a book on this topic that is she co-authoring and provided the editor's contact information.
- Gary Fellers, USGS, is an expert in herptiles rather than crossings. He provided additional contacts within USGS as well as the names of the major herpetological societies.
- David Grandmaison, Arizona Game and Fish Department, discussed the initial results of desert tortoise crossing research, in particular, findings regarding the different species of the desert turtle (*Gopherus agassizii* and *Gopherus morafkai*). He also shared new guidance developed for Arizona DOT about crossing structures to protect smaller animals, including herptiles.

Resources
We included nearly 50 citations dating from 2001 to 2012. With Caltrans' existing annotated literature search focused on research, we focused more on practitioner guidance for this Preliminary Investigation. Guidance on this topic is presented in the following sections:

- **Design Guidance** includes guidebooks on this topic. These include national guidance (notably the United States' primary federal guide, FHWA's Wildlife Crossing Structure Handbook: Design and Evaluation in North America, as well as guidance from the USDA Forest Service, USGS and AASHTO) and practices of state agencies (Arizona, Florida and Maine). We cite in detail passages that specifically address herptiles.
- **International Guidance** includes four resources: one from Australia (in press), two from Germany that represent federal guidance in that country and findings from the FHWA international scan on European practices.
- Research citations that address herptiles are divided into the following groups:
    - **Herptile Crossing Research: Design, Placement and Evaluation** addresses various aspects of mitigation, from identifying roadkill hotspots for herptile crossings to methodologies for evaluating efficacy of mitigation measures.
    - **Herptile Road Ecology** includes research relevant to this Preliminary Investigation that does not relate specifically to road crossing features. These issues include impacts of road networks on herptiles and population connectivity.
    - **Road Ecology of California Species** research includes four recent resources that address the desert tortoise.
    - The citation in **Aquatic Wildlife** addresses crossings for aquatic species that may also affect herptiles; this was a topic of secondary interest to Caltrans.
- **Additional Web Resources** provides a directory of state and federal government officials involved with transportation and ecology as well as an overview of the major herpetological societies.

Gaps in Findings

The three forthcoming books we learned about in the course of conducting this Preliminary Investigation suggest a high level of interest in herptile crossings as well as the absence of definitive guidance. As Caltrans expected and as our efforts revealed, crossing solutions are often site-specific and depend on the species to be protected, its habitat and life history, the local ecology, and the planned or existing roads in question. Balancing the needs to prevent roadkill and maintain connectivity is another complicating factor. No single guidance document that we found encompassed all of these factors and provided unambiguous design guidance. The lack of science-based guidance was stressed in particular by interview subject Tom Langton of Herpetofauna Consultants International.

In addition, our inquiries into different topics revealed little firm information about cost. In general the information that was available addressed strategies for securing funding and the relative costs of different mitigation efforts. One exception was our interview with Nevada DOT's Julie Ervin-Holoubek, who provided figures about the costs associated with desert tortoise fencing.

Next Steps

During the course of our interviews, several additional names were suggested as possible points of contact. Due to limitations on time and budget, we were unable to follow up with every individual suggested to us. Depending on the agency's specific interests for further information, Caltrans may wish to follow up with these individuals.

Some of the experts we spoke to are actively engaged in exploring the issues surrounding herptile crossings in a formal informational exchange. Tom Langton of Herpetofauna Consultants International discussed his presentations to USGS staff in California, and Sandra Jacobson mentioned her short course about this topic. There is an opportunity for Caltrans to engage in formal information exchange of this type with these experts or others.

Contacts

During the course of this Preliminary Investigation, we spoke to or corresponded with the individuals listed below:

Researchers

Carleton University
Lenore Fahrig
Professor, Department of Biology
Ottawa, Canada
(613) 520-2600, ext. 3856, lenore_fahrig@carleton.ca

Herpetofauna Consultants International
Tom Langton
Managing Director
Suffolk, United Kingdom
+44 79 6986 4641, t.langt@virgin.net

Laurentian University
David Lesbarrères
Associate Professor, Department of Biology
Sudbury, Canada
(705) 675-1151, dlesbarreres@laurentienne.ca

University of Florida
Ken Dodd
Courtesy Associate Professor, Department of Wildlife Ecology and Conservation
(352) 377-4319, caretta@ufl.edu

State DOTs

Arizona
Tom Kombe
Research Project Manager
Arizona Department of Transportation
(602) 712-3134, ekombe@azdot.gov

Florida
Vicki Sharpe
Wildlife and Habitat Programs Coordinator
Florida Department of Transportation
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Indiana
Dave Glista
Office of Environmental Services
Indiana Department of Transportation
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Nevada
Julie Ervin-Holoubek
Senior Wildlife Biologist
Nevada Department of Transportation
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New York
Debra Nelson
Environmental Analysis Bureau
New York State Department of Transportation
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Washington
Paul Wagner
Biology Branch Manager
Washington State Department of Transportation
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Other Government Agencies

Arizona Game and Fish Department
David Grandmaison
Research Biologist
(520) 609-2164, dgrandmaison@azgfd.gov

U.S. Department of Agriculture Forest Service
Sandra Jacobson
Wildlife Biologist
Pacific Southwest Research Station
(530) 759-1707, sjacobson@fs.fed.us

U.S. Geological Survey
Gary Fellers
Western Ecological Research Center
(415) 464-5185, gary_fellers@usgs.gov

Expert Interviews

Caltrans presented a list of possible contacts in and outside of California. We attempted to reach all of these individuals, and we also contacted others suggested through our correspondence or by our research.

Among experts and practitioners, we spoke with or corresponded with four **Researchers**, six representatives of **State DOTs** (including three states near California) and three representatives of **Other Government Agencies**.

Researchers

University of Florida

Contact: Ken Dodd, Courtesy Associate Professor, Department of Wildlife Ecology and Conservation, (352) 377-4319, caretta@ufl.edu.

We spoke with Ken Dodd about his experiences with protecting herptiles at highway crossings.

Paynes Prairie State Preserve research

> Dodd discussed the findings of his research reported in "Effectiveness of a Barrier Wall and Culverts in Reducing Wildlife Mortality on a Heavily Traveled Highway in Florida" (page 31). This study is of the road wall barriers and animal passage culverts in Paynes Prairie State Preserve, FL, that Lenore Fahrig of Carleton University also mentioned (page 9). Dodd said that the lipped walls were extremely effective in preventing animal roadkill. He also said that animal monitoring with motion sensors and cameras showed that the animals were using the underpasses.
>
> Dodd also noted some unique features of this project. The road was elevated through a wet prairie basin, and the animal barrier walls proved to be a stabilizing feature for the roads; this helped get the feature included in the design. In addition, the presence of alligators near culvert exits affected the mortality of smaller animals. (They also necessitated special fencing to prevent tourists' access to them.) He also said that there was increased animal mortality at the basin's rims due to engineering issues (slumping) that allowed animal access to the roadways.

Maintenance

> Dodd stressed the importance of long-term maintenance to keep solutions like those described above working as intended. For example, unchecked plant growth along the roadside can allow small animals—herptiles and mammals—to climb over the wall on the vegetation and access the road. Moreover, the passages need to be cleaned and maintained periodically. He described mitigation efforts as potentially a waste of money if a budget is not made available for the necessary follow-up work and for dedicated staff to carry out the work.

Design considerations

> A feature of the Paynes Prairie State Preserve experience that may be of interest to Caltrans was the length of the tunnels. Dodd noted that it was a long passage—across a four-lane divided highway—and a particular concern for amphibians is maintaining a sufficiently wet environment in the crossing.
>
> Dodd is co-author of an upcoming book, Amphibian Ecology and Conservation, and discusses passage design considerations in more detail in this excerpt of a draft from Chapter 27—Conservation and Management:

> The most effective way to assist amphibians across roads is to construct a barrier wall to prevent access, coupled with a series of underpasses, culverts, or tunnels to allow transit to the other side. … The walls serve to prevent trespass, while at the same time funnelling the migrating amphibians toward the underpass or culvert. Walls may be made of pre-cast concrete using a variety of lip (or overhang) designs to discourage climbing amphibians from crossing over the wall; slick, rather than rugose, surfaces also help to discourage climbing. The size of the culverts has varied among projects, but most provide for light and moisture access (to prevent animals from desiccating and provide an incentive for them to enter) and a moist dirt, mud or water substrate. Culverts or tunnels may be built well under a raised road bed, or even level with a roadway surface with a grate forming the ceiling when raised road beds are not present; a permanent barrier wall need not be present. In such cases, drift fences constructed of highway cloth or sheet plastic can be used to funnel amphibians toward the underpass. Some amphibians will enter even narrow tunnels and successfully cross a highway, but others may require culverts of more than 1 m diameter. The length of the culvert may have important effects of the propensity of an amphibian to enter and cross successfully. For long culverts, as across more than four lanes, the underpass might have to be constructed in sections, and access to light and moisture become critical. Entrances should allow easy access in both directions, and brush or other woody debris may provide retreat sites and refuges from predators.

This book appears to be a 2013 update of the existing publication Amphibian Ecology and Conservation: A Handbook of Techniques. The complete draft chapter has been provided to Caltrans in the Supplement to this Preliminary Investigation.

During our interview, Dodd stressed that mitigation efforts are necessarily site- and species-specific; other examples he mentioned were the culvert underpass system in Lake Jackson, FL, which successfully allowed passage of freshwater turtles, and crossing passages for garter snakes in Alberta, Canada. At the same time, Dodd noted, designers are not usually designing passages for just one species but for several animals in the local ecosystem.

Carleton University (Ottawa, Canada)
Contact: Lenore Fahrig, Professor, Department of Biology, (613) 520-2600, ext. 3856, lenore_fahrig@carleton.ca.

Lenore Fahrig's research has included methodologies for studying the efficacy of animal crossings. As noted in her journal article "The Rauischholzhausen Agenda for Road Ecology" (page 33), these solutions are seldom tested rigorously by road agencies.

Effectiveness of available crossings

Fahrig described work done by her research team, not yet published, to assess the impact of box culverts as highway crossing for frogs and the effect on mortality. In a controlled study, frog mortality rates were measured at 20 existing culvert sites along 36 kilometers of highway. Ten culverts were undisturbed as a control group, four were screened over to prevent frog passage, and six were bounded by 90 meters of road fencing on either side to prevent crossing anywhere except through the culverts.

By analyzing before-and-after mortality data, the research team found that adding screening (that is, blocking passage through culverts) did not affect frog mortality rates. However, the team found that adding fencing on the sides of culverts decreased mortality. Researchers concluded that measures to prevent on-road crossing had a much larger effect than structures that could allow alternative passage.

While this study only involved local frogs, Fahrig suspected that similar results would be seen for small reptiles and animals that don't adapt to redirect their own movements toward crossing structures.

Mortality versus connectivity

The findings of this study relate to what Fahrig described as an unacknowledged debate in the literature about mortality versus connectivity: What is the relative concern of preventing animals from dying on roads compared with preventing population fragmentation? She said that modeling work shows that many animal populations are not affected by road density, and subdivision of their populations tend not to have an effect on total population density.

Fahrig said that in most cases, mortality is most important, and the first priority is keeping animals off the road. If roadkill mitigation efforts have a secondary effect of providing passage across (over or under) the road, that is an added benefit. This is true as well for threatened species. When small population size is a concern, directly preventing animal death is typically the greater priority.

During this discussion, Fahrig mentioned the effectiveness of the lipped concrete wall at Paynes Prairie State Preserve, which has been very effective in preventing reptile roadkill. (See image at http://www.fhwa.dot.gov/environment/critter_crossings/photo39.cfm.)

Variation by species

Fahrig discussed how effects of roads on animals are dependent on species and their behaviors. She co-authored a meta-analysis of 75 studies (page 32 of this report). Among the major animal groups, herptile populations show the largest negative impacts of roads, stronger than the effects on mammals or birds.

Laurentian University (Sudbury, Canada)
Contact: David Lesbarrères, Associate Professor, Department of Biology, (705) 675-1151, dlesbarreres@laurentienne.ca.

David Lesbarrères' research focuses on the evolution and ecology of amphibian populations. Lesbarrères and Fahrig co-authored the paper "Measures to Reduce Population Fragmentation by Roads: What has Worked and How Do We Know?" (page 27).

Planning for mitigation features

Lesbarrères stressed the variation in herptile behavior—from species to species and even within species located in different environments. This kind of variation makes it difficult to successfully apply a given solution to another location. Some generalities can be used as guidelines (for example, turtles need a place to lay eggs, amphibians need breeding ponds), but this information is not enough to inform proper planning of mitigation features (barriers, crossings or both) at a specific road site.

Like Fahrig, Lesbarrères noted that there are two related issues: How to keep animals off the road and prevent roadkill, and how to keep populations connected to allow passage to critical habitats and not disrupt mating and gene flow.

He said that a critical step in designing roads and mitigation features is to conduct a population study in the area under consideration. Questions to consider: Which species are present? What is the status (size) of the populations on either side of the planned highway? Where are their critical habitats (breeding, feeding, hibernation)? Answers to these questions inform both aspects of mitigation.

Retrofitting versus new roads

When retrofitting existing roads with mitigation features, identifying crossings and roadkill hotspots is a straightforward process and can be accomplished by collecting roadkill data. To get a complete picture of the critical crossing areas, data should be collected for a full year and sorted by season and by sex of the killed animals when possible.

For planned roads, tagging and GPS tracking of the species in question is a good way to collect telemetry data on a local population home range, critical habitats and likely crossing areas with respect to planned highways. Data might vary by season, so ideally a study of such a population would last at least an entire year, and at the very least during the seasons when the species of concern are known to disperse. The goal is to be able to preserve and connect the critical portions of the habitat when designing the road, animal barriers and animal crossings. Lesbarrères said this kind of tracking has been conducted successfully for turtles and snakes. His research team is now working on a before-after-control-impact design to measure the impacts of crossings on a turtle population.

Practical guidance

Lesbarrères is contributing a chapter (Making a Safe Leap Forward—Mitigating Road Impacts on Amphibians) to a new guide to be published soon. (See page 25 of this report.) The complete draft chapter has been provided to Caltrans in the Supplement to this Preliminary Investigation. The guide will provide an overview of current practice in tunnel design and next steps. It will be geared toward practitioners with step-by-step recommendations for mitigation, maintenance and monitoring. The five key findings are:

- Planning the location of new roads is critical.
- Design and placement of road-crossing structures are paramount.
- Road construction must be timed.
- Road crossing structures and fences must be maintained.
- The effectiveness of mitigation for amphibians can only be determined by long-term monitoring.

When asked about costs involved, Lesbarrères said that the book, though not necessarily his chapter, may address cost issues. In general, however, the costs of conducting the types of population and behavior studies discussed above are small, he said—perhaps a few graduate student salaries and the cost of telemetry hardware—compared with the millions required to build the roads.

Herpetofauna Consultants International (Suffolk, United Kingdom)

Contact: Tom Langton, Managing Director, +44 79 6986 4641, t.langt@virgin.net.

Tom Langton co-authored the chapter about mitigating road impacts on amphibians with David Lesbarrères. (See our interview above.) He is writing a 40,000-word review of small ecopassages for vertebrates in a forthcoming book from Johns Hopkins Press on this topic. (See our interview with Sandra Jacobson on page 15 of this report.)

Langton noted that the national guidance in the United States (FHWA's Wildlife Crossing Structure Handbook: Design and Evaluation in North America, on page 19 of this report) is not based on much scientific data. To do this topic justice, he said, a good step would be to spend a day sharing what's known and done throughout the world—Europe, Australia and North America, in particular—as he did with the USGS in March 2012 during a training day in San Diego. Langton's introduction to the Johns

Hopkins Press book will also address this topic in detail and should be drafted by the end of the year. In addition, Langton shared the German federal guidelines on amphibian crossings, Merkblatt zum Amphibienschutz an Straßen (Bulletin on Amphibian Protection on Roadways) (page 25 of this report).

Some additional points from our discussion with Langton include the following:

- A great deal of work has been done on animals, but little has been written from the "roads' perspective": What factors need to be considered regarding crossings when designing and building roads?
- The best approach for implementing crossings for herptiles and small mammals is the use of multipurpose structures designed to serve both as drainage structures and animal crossings. This unified approach makes the most sense in terms of resources, design and acceptance.
- More work needs to be done on developing science-based design guidance for herptile crossings. It can be approached in a number of ways, and it's important to get it done right.

He is involved with research on species in the California area, including snakes and long-toed salamanders. He expects to be back in California in summer 2013 to conduct additional training.

State DOTs

Arizona

Contact: Tom Kombe, Research Project Manager, Arizona Department of Transportation, (602) 712-3134, ekombe@azdot.gov.

We corresponded with Arizona DOT's Tom Kombe, asking in particular about the research project Predicting Desert Tortoise (*Gopherus agassizii*) Habitat and Identifying Movement Patterns within the Proposed Highway 95 Realignment (page 34 of this report). He wrote:

> *The subject project has not published. It is in final report technical editing towards publication. Also, the design and placing of crossing was not a key aspect of this study effort. Until the report is published I'd suggest you get in touch with the lead researcher, David Grandmaison, Research Biologist with the Arizona Game and Fish Department.*

Our interview with Grandmaison is summarized on page 18 of this report.

Florida

Contact: Vicki Sharpe, Wildlife and Habitat Programs Coordinator, Florida Department of Transportation, (850) 414-5326, vicki.sharpe@dot.state.fl.us.

Vicki Sharpe noted that although Florida has constructed numerous wildlife crossing structures around the state (primarily for terrestrial wildlife species such as panther, black bear, deer and bobcat), to date only a few of these structures have been built to specifically accommodate herptile species. Noteworthy examples in her state include Paynes Prairie ecopassage (see page 7 of this report); a crossing primarily designed to accommodate turtle passage in Lake Jackson; and another passage for newts, frogs and other herptiles across U.S. Highway 319 in Leon County. Additional herptile crossing structures are currently being proposed for future transportation projects.

Sharpe shared several thoughts with us on this topic:

- Florida works closely with regulatory agencies early in the planning process for herptile crossing and roadkill mitigation efforts. The state fish and wildlife agency helps the DOT develop management plans for species and reviews projects early in the process. This work is supported by an extensive GIS network and a robust environmental screening tool.

- Premonitoring of a site is necessary to determine and document the need for mitigation efforts. It also informs placement, design, size and dimension of the animal crossing and barriers.
- When retrofitting, a careful environmental study is important to ensure that adding a crossing will not cause more harm than good. An engineering study helps define what's possible given the existing conditions.
- From a funding standpoint, it is better to include funding for mitigation as part of the initial project planning. It is much harder to secure funds for this purpose later in the process, such as during the permitting stage.

Florida provides high-level guidance in its publication Florida Department of Transportation Wildlife Crossing Guidelines (page 21 of this report). Sharpe noted that because each crossing has unique engineering and ecological challenges, the state has not developed a detailed design manual. Even though the three examples in the state noted above share similar traits (for example, all use barrier walls), there is no one-size-fits-all solution.

Additional Contacts

For additional expertise on this topic, Sharpe suggested the following contacts:

Scott Jackson
University of Massachusetts Amherst
Department of Environmental Conservation
(413) 545-4743 ext. 328
sjackson@umext.umass.edu

Bruce Means
Coastal Plains Institute and Land Conservancy
President and Executive Director
(850) 681-6208
means@bio.fsu.edu

Patricia Cramer
Utah State University
Research Assistant Professor, Wildland Resources Department
(435)797-1289
patricia.cramer@usu.edu

Related Resources

"Completed Environmental Management Research Projects," Research Center, Florida Department of Transportation, undated.
http://www.dot.state.fl.us/research-center/Completed_EMO.shtm
Florida DOT's environmental research findings are available at the web page.

Below are several resources that Sharpe considers of value. Full citations for all are included in the **Resources** section of this report:

- Monitoring Wildlife Use and Determining Standards for Culvert Design (page 31 of this report).
- Reducing Impacts on Rare Vertebrates that Require Small Isolated Water Bodies along U.S. Highway 319 (page 32 of this report).
- Evaluation of the Use and Effectiveness of Wildlife Crossings (page 30 of this report).

- Wildlife Crossings: The State of the Science—A Literature Review (page 30 of this report).
- Wildlife Crossing Structure Handbook: Design and Evaluation in North America (page 19 of this report).
- Wildlife-Vehicle Collision Reduction Study: Best Practices Manual (page 22 of this report).
- Wildlife and Roads web site (page 24 of this report).
- Guidelines for Culvert Construction to Accommodate Fish and Wildlife Movement and Passage, Arizona Game and Fish Department (page 24 of this report).
- Proposed Design and Considerations for Use of Amphibian and Reptile Tunnels in New England (page 32 of this report).

Indiana

Contact: Dave Glista, Office of Environmental Services, Indiana Department of Transportation, (317) 234-5241, dglista@indot.in.gov.

We corresponded via email with Dave Glista, who co-authored "A Review of Mitigation Measures for Reducing Wildlife Mortality on Roadways" (page 30 of this report) and "Vertebrate Road Mortality Predominantly Impacts Amphibians" (page 33 of this report). Glista wrote:

> *Our research project did not actually test structures for their effectiveness; my manuscript was really more of an exploratory study into what species are getting killed on roads in Indiana. The paper "A review of mitigation measures for reducing wildlife mortality on roadways" was meant to be a literature review for my thesis. That said, I'd like to hear about some of Caltrans' current issues and what you might have in mind for solutions. I'm by no means an expert but I'd sure try to lend a critical eye or ear to the problem. It's tough to find adequate chunks of time to talk. However, if you wouldn't mind detailing some of the issues you're facing in an email or something similar, I could print it and then get back to you once I've had a chance to digest it. I still have a few connections at my alma mater that may also be able to give some advice if necessary.*

Regarding his papers, Glista wrote:

> *I know there is newer stuff out there as the transportation ecology field has grown. You might look to the Oregon and Washington DOTs for some reference material, too. I think most of their work was with large mammals, but I sat through a webinar presentation that they were a part of and I really liked what they were doing. There has also been some interesting herptile work in the northeast, Massachusetts and Vermont come to mind, as well as Florida.*
>
> *Question: Is Caltrans trying to put together justification for a herptile (or any other taxa) structure or structures or are they looking into a long-term type program?*

Caltrans may wish to contact Glista directly with specific questions on this topic after reviewing the findings in this Preliminary Investigation.

Nevada

Contact: Julie Ervin-Holoubek, Senior Wildlife Biologist, Nevada Department of Transportation, (775) 888-7689, jervin-holoubek@dot.state.nv.us.

According to Julie Ervin-Holoubek, most herptile connectivity work in Nevada involves preventing habitat fragmentation for desert tortoises. The state uses culverts for this purpose, utilizing a larger size than would typically be used for drainage culverts. Ervin-Holoubek said that the state has design specifications for these culverts that she can make available to Caltrans. The state does not differentiate its requirements for the Sonoran and Mojave species of desert tortoise.

The state also currently maintains more than 400 miles of exclusion fencing for desert tortoises. Ervin-Holoubek noted that according to the U.S. Department of Fish and Wildlife's guidance (Desert Tortoise Field Manual, Chapter 8—Desert Tortoise Exclusion Fence, available at http://www.fws.gov/ventura/species_information/protocols_guidelines/docs/dt/dt_fieldmanual/CHAPTER%208.pdf), this fencing needs to be checked on a quarterly basis. The costs for monitoring and repair are significant: approximately $200,000 per year. Monsoon flooding is the primary cause of damage to the fencing.

Ervin-Holoubek said that the agency has conducted some evaluation of the effectiveness of existing tortoise passages. The ability of tortoises to see light is an issue for whether they will use a tunnel, but exact thresholds are unknown. The experience has been that tortoises will generally use tunnels less than 100 feet long on their own. Ervin-Holoubek also said that drop inlets have been used at road medians to allow light into longer culverts.

Beyond tortoises, Ervin-Holoubek also mentioned that the Nevada DOT and others worked with federal and state wildlife offices to help protect the Amargosa toad in Beatty, NV. A 6-by-10-foot culvert through the town of Beatty serves as a toad crossing and also carries water flow during the monsoon months.

New York

Contact: Debra Nelson, Environmental Analysis Bureau, New York State Department of Transportation, (518) 485-5479, dnelson@dot.state.ny.us.

We spoke with Debra Nelson about the NYSDOT research project "Effects of New York State Roadways on Amphibians and Reptiles" (page 28 of this report). She said that the findings of this research affected the state's practices even while the study was being conducted. While some predictive modeling was done, the goal of developing a dynamic model was not achieved.

Nelson suggested possibly arranging a conference call with the key New York technical staff and practitioners if Caltrans would like to learn more about the process and outcome of this research.

Washington State

Contact: Paul Wagner, Biology Branch Manager, Washington State Department of Transportation, (360) 705-7406, wagnerp@wsdot.wa.gov.

We corresponded with Paul Wagner, who wrote:

> *I suggest you spend some time looking at proceedings from the [International Conference on Ecology and Transportation] conferences if you have not. I also think it would probably be useful to consider species groups with similar connectivity needs. Herps cover a big range and some like desert tortoise, have very different needs [from others] like aquatic salamanders.*
>
> *We don't really have crossings that are constructed solely for herps, but we have many built for stream simulation and other methods of fish passage that accommodate herps well as well as culverts that they use that were probably never placed with that in mind. I think the important thing [is] to think about connecting habitats more than the mechanics of individual species. Methods like stream simulation try to mimic natural channels and are a good way to cover the needs of many species.*

Other Government Agencies

U.S. Department of Agriculture Forest Service

Contact: Sandra Jacobson, Wildlife Biologist, Pacific Southwest Research Station, (530) 759-1707, sjacobson@fs.fed.us.

We spoke with Sandra Jacobson, the Forest Service's subject matter expert for transportation ecology. Based in Davis, CA, Jacobson is closely involved with the agency's web site Wildlife Crossings Toolkit (http://www.fs.fed.us/wildlifecrossings; see page 20 of this report).

General guidance

Jacobson is among several authors of a forthcoming book about road ecology for small animals, particularly for herptiles. In a follow-up email to our conversation, Jacobson wrote:

> *Kimberly Andrews is a herpetologist and one of the editors of the Partners in Amphibian and Reptile Conservation book on small animals and roads. She can tell you more about the book, and she also is a great person to talk to about the topic of herps and roads. Her experience is more from the southeastern United States, but many of the concepts are universal.*
>
> *Contact information:*
>
> *Kimberly M. Andrews, Ph.D.*
> *UGA Savannah River Ecology Laboratory*
> *(803) 725-9793, andrews@srel.edu*

The book is discussed in more detail in "Road Planning and Mitigation Design for Small Animals: Concepts and Applications," a conference paper presented at the International Conference on Ecology and Transportation in 2011 (www.icoet.net/ICOET_2011/documents/proceedings/Session-CRB-3.pdf). Jacobson expects the book will be published by Johns Hopkins Press in spring 2013.

Jacobson also described the FHWA Central Federal Lands publication Wildlife Crossing Structure Handbook: Design and Evaluation in North America (page 19 of this report) as credible and among the best state-of-the-art guidance on animal crossings. The manual reflects that much more is known about large species than small ones.

Biological and design considerations

Jacobson said that from a pragmatic standpoint, placing herptile crossings comes down to funding, political will and opportunity:

- *Funding* for herptile crossings is often much less expensive than crossings for deer and other larger animals; it is often simple and inexpensive.
- Beyond the mandate to mitigate roadkill for certain species due to their legal status, *political will* can also be provided by local groups concerned with herptile welfare.
- *Opportunity* is based on a determination of where crossings are needed and can do the most good. Among the factors to consider are the species involved and the threats to the population, the topography, time in season, and when and how they are likely to move.

She said that one of the unique challenges for Caltrans is its ecological diversity, describing it as a microcosm of all geographic regions. As with other experts we spoke to, she commented that there is not a one-size-fits-all solution for herptile crossings. Even similar animals have key differences that could have a major impact on crossing design.

Jacobson teaches a short course on this topic; during our discussion she provided some highlights of key issues:

Reproductive Potential—Different species have different innate breeding strategies. Those that are short-lived, produce a lot of offspring and generally provide little parental effort (such as many types of frogs) have high reproductive potential. By contrast, long-lived animals that produce few young have low reproductive potential (for example, many turtles and tortoises). Those with low reproductive potential are particularly vulnerable to mortality in environments that they are not adapted to, such as roadways. Jacobson said it does not take much to extirpate (locally exterminate) a population of a slow-moving species that needs to make a seasonal highway crossing in order to lay eggs. It is critical to understand which species populations are most at risk (and which, by contrast, might actually be very tolerant to roadkill losses).

Antipredator Adaptations—How species respond to threats plays a critical role. Whether animals ignore or respond to traffic and how they respond (pause, speed away or avoid) all play a role in highway mortality and have an impact mitigation design on a species-by-species basis. Jacobson has conducted research exploring the mortality effect of this antipredator response as traffic volume varies; the findings will be published soon. "A Conceptual Framework for Assessing Barrier Effects to Wildlife Populations Using Species Group Responses to Traffic Volume," a poster she presented on this topic in 2009, is attached to this Preliminary Investigation as Appendix B.

Limitations on Roadkill Data—Jacobson stressed caution in interpreting animal roadkill data. She noted that lack of dead animals on or near roadways could possibly mean that mitigation efforts are working successfully, but it could also mean that a species has been extirpated.

Crossing Suitability—Suitability is an important factor for crossings, since herptiles are impacted by temperature, light and humidity, and some navigate by celestial cues. For example, for species that need to see the sky, animals might stop or turn around if the structure does not provide openings to the sky. Some animals move with rain events and need contact with precipitation for crossing. Other animals that need to stay wet will dry up in a long and well-drained tunnel. In structure design, the substrate material must be considered: Heavy metals can be absorbed through some herptiles' skin and are poisonous to them.

Combining Barriers and Crossings—Jacobson said that the most effective way to prevent roadkill is a combination of barriers and suitable crossings. A fence or wall serves two purposes: both as a barrier and a diversion to drive animals to the crossing.

Types of Animal Movement—Jacobson described three distinct types of animal movement and discussed the varying importance of the mobility of the entire population:

- The *daily/seasonal* need to move (that is, the life history need) involves movement to and from breeding habitats or food sources. If most of the population is not allowed to move as required for these purposes, population numbers are likely to suffer.
- For *metapopulation dispersal*, or the dispersement of young or the recolonization of extirpated areas, it is less necessary for every member of a population to be able to move.
- *Genetic interchange dispersal* involves occasionally connecting separated populations to maintain genetic diversity. Though generally desired, this might not be strictly necessary if separated populations are healthy on both sides.

Aquatic Organism Passages—Jacobson said that the Forest Service and others have undertaken significant work to retrofit or replace water structures to allow aquatic organism passage. She said passages for aquatic organisms that include a stream simulation model are generally good for terrestrial herptiles that live in or by the side of the stream. However, any assumption that these passages will be effective for other salamanders or upland herptiles (such as snakes) is not necessarily true. For example, some terrestrial salamanders will drown in water.

U.S. Geological Survey

Contact: Gary Fellers, Western Ecological Research Center, (415) 464-5185, gary_fellers@usgs.gov.

Gary Fellers noted that he is not an expert in herptile crossings; he works with a number of endangered species, including amphibians and reptiles in California. He said that for certain species, including some listed as protected or endangered, crossing roadways between breeding and nonbreeding areas can result in high mortality.

Fellers stressed that the impact is very site- and species-specific. Some animal species he works with are not in areas that would be impacted by Caltrans roads. In other cases, roadways have a significant impact on species that migrate en masse at certain times or under specific conditions. Species he mentioned by name include the tiger salamanders, long-toed salamanders and spadefoot toads.

Beyond California, one mitigation strategy that Fellers is familiar with is the use of tunnels running under roadways as garter snake crossings in Canada and the northern Midwest. Another strategy involves under-road crossings aimed at reducing toad mortality in Great Britain.

Fellers mentioned the three major societies concerned with herpetology:

- The Herpetologists' League
  http://www.herpetologistsleague.org/en/
- Society for the Study of Amphibians and Reptiles
  http://www.ssarherps.org
- American Society of Ichthyologists and Herpetologists
  http://www.asih.org

He noted that these groups meet regularly and sometimes jointly, and abstracts from their journals and annual meetings would likely include information of interest regarding understanding how specific animals move and migrate within their habitats. He also noted that the World Congress of Herpetology (http://www.worldcongressofherpetology.org) was held in Vancouver in August 2012.

As additional contacts, Fellers suggested two California-based USGS staff members, both with the Western Ecological Research Center, who have worked extensively with reptiles:

Kristin Berry
Supervisory Research Wildlife Biologist
Box Springs Field Station, USGS Western Ecological Research Center
(951) 697-5361, kristin_berry@usgs.gov

Robert Fisher
Biologist
San Diego Field Station, USGS Western Ecological Research Center
(619) 225-6422, rfisher@usgs.gov

Arizona Game and Fish Department

Contact: David Grandmaison, Research Biologist, (520) 609-2164, dgrandmaison@azgfd.gov.

As Tom Kombe with Arizona DOT suggested, we spoke with David Grandmaison of the Arizona Game and Fish Department (AZGFD). Grandmaison said that AZGFD works closely with highway agencies in the state, including the state DOT but also county and municipal agencies. AZGFD conducts hot spot analysis to determine where animal crossings would be effective, and before-and-after studies using telemetry data to measure the effectiveness of crossings. Grandmaison stressed the importance of considering connectivity measures early during the planning and design stages for highway construction or widening.

We discussed two projects that Grandmaison conducted in Arizona involving herptiles:

- Wildlife Linkage Research in Pima County: Crossing Structures and Fencing to Reduce Wildlife Mortality (page 27 of this report). Prior to this project, much of the focus in Arizona had been on protecting threatened and endangered species and protecting large animals that present the greatest safety threat to motorists. This report takes a more holistic, ecosystem-based approach that considers all animals, including the smaller animals that comprise herptiles. Grandmaison noted that there hasn't been much opportunity yet to put the findings in this report into practice.

- Predicting Desert Tortoise (*Gopherus agassizii*) Habitat and Identifying Movement Patterns within the Proposed Highway 95 Realignment (page 34 of this report). Although this report is noted as "in progress," it was completed in 2010, and Grandmaison expects Arizona DOT to publish it soon. He described it as two studies: One examined the effectiveness of adding fencing to existing crossing structures for desert tortoises, and the other recommended possible crossing placements for a new road based on the mobility behavior of the tortoise population at the site.

  Grandmaison cautioned against overgeneralizing from research results based on site- and species-specific data. In the case of this research, he noted possible differences between two separate species of desert tortoise (*Gopherus agassizii* common to California and parts of Arizona, and *Gopherus morafkai* found elsewhere in Arizona); some overlap of genotypes among the population studied in this project is addressed in the report.

Resources

In this section we present a range of resources, including guidance documents, research reports and web sites. Resources are grouped into several categories. **Design Guidance** includes guidebooks on this topic. Because some of these publications provide guidance beyond herptiles, we have cited specific passages that will be of interest to Caltrans. **International Guidance** is a separate category that lists references from Australia and Europe.

Research citations are herptile-specific and divided into thematic groups. Publications that address aspects of mitigation appear under **Herptile Crossing Research: Design, Placement and Evaluation**. General research not specific to crossing features but relevant to this Preliminary Investigation appear under **Herptile Road Ecology**. Research publications under **Road Ecology of California Species** address the desert tortoise. One additional citation is presented in the section **Aquatic Wildlife**.

Links to a directory of government officials and to major herpetological societies appear under **Additional Web Resources**.

We did not attempt to include in full all of the citations included in Caltrans' own extensive review of literature, Appendix A, which includes more than 80 individual references. Instead, we selected those that appeared both highly relevant and timely (within the past three years) as well as those referenced in our communications with experts.

A majority of the nearly 50 citations below do not appear in Caltrans' review of literature. We have marked each citation for quick reference:

- Citations marked with an asterisk (*) *do not appear* in Appendix A.
- Citations marked with a dagger (†) *do appear* in Appendix A.

Design Guidance

***Wildlife Crossing Structure Handbook: Design and Evaluation in North America**, Federal Highway Administration, Central Federal Lands Highway Division, Publication No. FHWA-CFL/TD-11-003, March 2011.
http://www.cflhd.gov/programs/techDevelopment/wildlife/documents/01_Wildlife_Crossing_Structures_Handbook.pdf
This handbook states that it "provides numerous solutions to wildlife-vehicle interactions by offering effective and safe wildlife crossing examples." The main chapters of the handbook address wildlife populations and road corridor intersections; impact identification, remediation, planning and placement; designs, guidelines and practical applications; and monitoring techniques and data analysis.

In addition, Appendix C—Hot Sheets lists different wildlife crossings, including fencing and gate details.

Hot Sheet 11—Amphibian/Reptile Tunnel (page 159) provides general design considerations, use guidelines, dimensions and design details, considerations for a guiding wall or fence, local habitat management and maintenance guidelines. Species-specific guidelines are broken down for amphibians and reptiles.

Other types of crossings recommended for or adaptable to herptiles (with varying applicability to reptiles versus amphibians) include:

- Hot Sheet 1—Landscape Bridge.
- Hot Sheet 2—Wildlife Overpass.

- Hot Sheet 3—Multi-Use Overpass.
- Hot Sheet 5—Viaduct or Flyover.

Other structures may also be appropriate for reptiles. Several hot sheets note that designers should "maximize microhabitat complexity and cover within the underpass using salvage materials (logs, root wads, rock piles, boulders, etc.) to encourage use by semi-arboreal mammals, small mammals, reptiles and species associated with rocky habitats":

- Hot Sheet 6—Large Mammal Underpass.
- Hot Sheet 7—Multi-Use Underpass.
- Hot Sheet 8—Underpass with Waterflow.
- Hot Sheet 9—Small-to-Medium-Sized Mammal Underpass.

Likewise, for Hot Sheet 10—Modified Culvert, "Semi-arboreal, semi-aquatic and amphibian species may use the structures if they are adapted for their needs."

***Wildlife Crossings Toolkit**, U.S. Department of Agriculture Forest Service, U.S. Department of Interior National Park Service, last modified Oct. 26, 2011.
http://www.fs.fed.us/wildlifecrossings
From the web site: The Wildlife Crossings Toolkit provides information for terrestrial biologists, engineers, and transportation professionals to assist in maintaining or restoring habitat connectivity across transportation infrastructure on public lands.

Among the main resources found at this web site are:

- Decision Support—Large Scale.
- Decision Support—Project Level.
- Integrated Planning.
- Examples.
- Retrofitting Existing Structures.
- Monitoring.
- Funding.

***Safe Passages: Highways, Wildlife, and Habitat Connectivity**, Jon P. Beckmann, Anthony P. Clevenger, Marcel P. Huijser, Jodi A. Hilty (editors), 2010.
http://books.google.com/books?id=dgiq9UnHVf4C
From the online summary: [This book presents] the latest information on the emerging science of road ecology as it relates to mitigating interactions between roads and wildlife. This practical handbook of tools and examples is designed to assist individuals and organizations thinking about or working toward reducing road-wildlife impacts.

A section on amphibian and reptile tunnels appears in Chapter 2—Wildlife Crossing Structures, Fencing, and Other Highway Design Considerations, and is excerpted below:

> The main conflicts with amphibians and reptiles are where roads intercept periodic migration routes to breeding areas or areas where young are produced (ponds, lakes, streams, or other aquatic habitats). For some species the migration to these critical areas, including the dispersal of juveniles to upland habitats, is synchronized each year. This large movement event results in a massive migration of individuals in a specific direction during a short period of time. Amphibian and reptile tunnels should be located in these key sections of road that intercept their movements year after year.
>
> Although they are designed specifically for passage by amphibians and reptiles, other small- and medium-sized vertebrates may use these tunnels as well. There are many different tunnel designs

to meet the specific requirements of each species or taxonomic group. Amphibians and reptiles tend to have special requirements for wildlife crossing design since they are unable to orient their movements to locate tunnel entrances. Walls or fences play a critical function in intercepting movements and directing animals to the crossing structure (Langton 1989).

Large tunnels provide greater airflow and natural light conditions; however, smaller tunnels with grated slots for ambient light and moisture can be effective. Grated tunnels are placed flush with the road surface. Requirements for tunnel design and microhabitat differ among amphibian and reptile taxa (see Lesbarrères et al. 2003). Hesitancy and repeated unsuccessful entry attempts at tunnels are believed to be due to changes in microclimatic conditions, particularly temperature, light, and humidity, that animals perceive as localized climate degradation. Larger tunnels (ca. 0.9 meters [3 feet] diameter) permit greater airflow and increased natural light at tunnel exits. Smaller tunnels can be effective if they are grated on top, increasing natural light and moisture. Sandy soil (sandy loam) should be used to cover the bottom of the tunnel to provide a more natural substrate for travel.

Amphibians have been documented using tunnels that range in length from 6.7 m (22 feet) (spotted salamanders *Ambystoma maculatum*, Massachusetts) to 40 m (125 feet) (Lausanne, Switzerland). The effectiveness of long tunnels spanning four-lane highways has not been tested. Shorter tunnels are better for amphibian movement.

Drift fencing. Because amphibian and reptiles generally do not avoid roads and have biased, directed movements while migrating, guiding walls or drift fences should be installed to direct movement toward the tunnel (Woltz et al. 2008). These walls should angle out from each end of the tunnel at approximately 45 degrees, at 1.25 feet high and be made of concrete, treated wood, or other opaque material. Guiding walls/fences made of translucent material or wire mesh are not recommended because some amphibians and reptiles try to climb over them instead of moving toward the tunnel.

The bottom section of a guiding wall or fence should be secured to the ground, not leaving any gaps. The guiding wall/fence should be tied into the tunnel entrance, avoiding any surface irregularities that might impede or distract movement toward the tunnel entrance.

***Wildlife Crossing Guidelines**, Florida Department of Transportation, 2009.
http://www.dot.state.fl.us/emo/pubs/APPROVED-Wildlife%20Crossing%20Guidelines3-13.pdf
As discussed with Vicki Sharpe in **Expert Interviews**, this publication provides high-level guidance for wildlife crossing decision-making in Florida.

***Amphibian Ecology and Conservation: A Handbook of Techniques**, C. Kenneth Dodd Jr. (editor), 2009.
http://books.google.com/books?id=nthpPgAACAAJ
From the online summary: This practical manual of amphibian ecology and conservation brings together a distinguished, international group of amphibian researchers to provide a state-of-the-art review of the many new and exciting techniques used to study amphibians and to track their conservation status and population trends.

An updated edition of this publication, currently in press, is addressed in our discussion with Ken Dodd in **Expert Interviews**.

***"Designing to Accommodate Wildlife, Habitat Connectivity, and Safe Crossings,"** Section 3.4, Compendium of Environmental Stewardship Practices in Construction and Maintenance, AASHTO Center for Environmental Excellence, 2008.
http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/3_4.aspx
Section 3.4—addresses the following topics:

- Identifying locations for wildlife crossings.
- Monitoring wildlife crossings.
- Wildlife crossing research, resources and techniques.
- State DOT initiatives to address wildlife habitat connectivity needs in planning and design.
- Maintenance and management of created, modified or restored habitat.

Excerpts from this resource provide herptile-specific guidance in the following areas:

> *Fencing*
> For reptiles and amphibians, bend the upper edge of the finer mesh at a 90-degree angle to provide a lip to prevent animals from climbing over the fence. In Waterton Park, Canada, a temporary silt barrier type fence was used to direct frogs into polyvinyl chloride (PVC) drop traps so that volunteers could move them across the highway to a pond during the few-week-long migration period. Europeans have used a PVC barrier with an angled lip to keep reptiles and amphibians off the highways as well as a fabricated galvanized steel rail with a barrier lip along the upper edge. Iowa DOT has placed finer mesh fence at the bottom of regular fence to prevent smaller wildlife such as turtles, snakes and other small animals from getting on the Eddyville Bypass and Highway 63 at the Bremer-Chicksaw county line. This fencing approach has been commonly used in Europe to keep smaller animals off highways.
>
> *Wildlife underpass bridges and dry culverts*
> A range of culvert sizes, from 1.22 m × 1.22 m (4 ft × 4 ft) in Arkansas up to 2.44 m × 7.32 m (8 ft × 24 ft) in Florida and from 1.5 to 10 m (4.92 - 32.81 ft) in New South Wales, Australia, have been successfully used for various species of terrestrial mammals and reptiles.
>
> *Extended bridges and existing structures*
> When choosing a combination of bridge and fill, consider what reptile and amphibian species will likely move up the fill slope onto the road. Standard fencing will not stop this movement so that very expensive barrier walls and associated guard rails may be necessary to prevent significant kills of these species during periods of the year when they are moving around in large groups.

***Wildlife-Vehicle Collision Reduction Study: Best Practices Manual**, M. P. Huijser, P. McGowen, A. P. Clevenger, R. Ament, Report No. FHWA-HEP-09-022, 2008.
http://environment.fhwa.dot.gov/ecosystems/wvc/index.asp#toc
From the abstract: The study was to advance the understanding of the causes and impacts of [wildlife-vehicle collisions (WVCs)] and identify solutions to this growing safety problem. ... Design and implementation guidelines are provided for wildlife fencing, wildlife underpasses and overpasses, animal detection systems, vegetation management and wildlife culling. Additionally for a WVC reduction program, information is provided on regional planning, identification of priority areas, alignment and design considerations, guidelines for monitoring effectiveness of mitigations, and potential funding sources.

Note: The publication focuses on mitigation for larger animals.

***Waterway and Wildlife Crossing Policy and Design Guide**, third edition, Maine Department of Transportation, Environmental Office, July 2008.
http://www.maine.gov/mdot/env/documents/pdf/3rd%20edition%20-%20merged%20final%20version%207-01-08a1.pdf
This publication presents specific design guidance for different types of wildlife. Section 3C, Herptile Passage (page 35 of the guide), is excerpted below:

> Roadways are often cited as one of the contributors to the decline of these animals either directly through habitat destruction or road mortality, or indirectly by blocking access to critical habitat requirements (Forman, 2003).
>
> Herptiles are typically wide-ranging species relative to their body sizes, with frogs and salamanders home ranges requiring at least several acres, while some wide-ranging turtles traverse several square miles or more. To limit adult mortalities as much as possible, stream crossings located adjacent to vernal pools and other wetlands adjacent to streams should consider passage and funneling for species that depend on these isolated, seasonal forest pools, such as state-listed Blanding's and spotted turtles, spotted and blue spotted salamanders, and wood frogs. These animals spend the majority of their life in uplands away from the breeding pools; salamanders can travel over 2,600 feet to get from their forested habitat to the breeding pools. Because salamanders and other herptiles travel primarily over land and not in water environments, several factors should be considered during crossing design.
>
> Passage for organisms that use both terrestrial and aquatic environments can most simply be incorporated by maintaining natural substrate through the use of bottomless arches or boxes that span the waterway plus some or all riparian areas, or by upsizing existing drainage cross-culverts and backfilling them with native, natural bed material, loam and/or leaf-litter whenever possible. Drainage culverts may need to be designed so that the backfilled material is not washed-out during high water events, which may be avoided by providing a dry culvert above bankfull or flooding elevations, backfilling this structure with native substrate possibly from material grubbed from the project, or providing a dry "shelf" in the drainage culvert to provide passage "banks" during draining periods. Although dry shelves appear to be a relatively straightforward method of addressing herptile passage, they pose maintenance and construction challenges. Possible issues include confined space work subject to OSHA regulations, cost of hand-placing materials in confined spaces, longevity of mortared structures, and obstructions created by large woody debris common to most Maine streams.
>
> Research in the Northeastern U.S. has also shown that some source of light may be required in the passage in order for herptiles to use them and it is recommended that in-structure light be provided through surface grating in the median above the structures if possible (Jackson, 2003). To date, logistics, costs, and comprehensive research has limited this application in Maine.
>
> Funneling to the entrances of the structures may encourage use; this can be accomplished by incorporating wing walls, or fencing with jersey barriers or silt fence anchored into the slope and backfilled. An example of funneling system used with crossings is diagramed in Figure 6.

Figure 6. Example of Funneling System for Herptile Passage

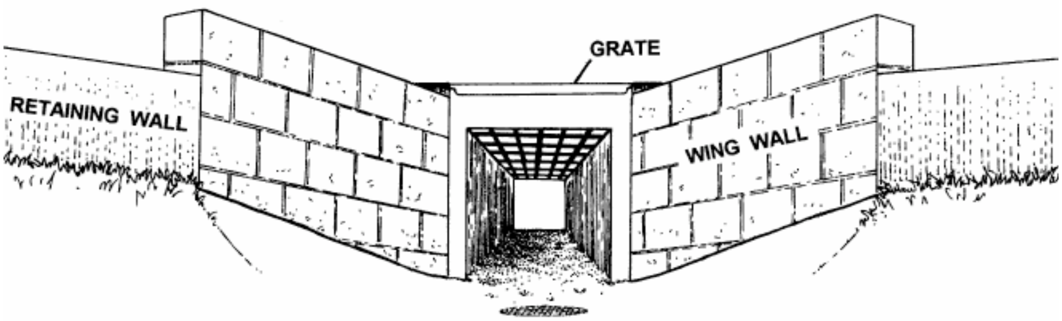

Figure 7. Arch culvert with funneling wall for herptiles and fencing for larger wildlife. Germany.

***Guidelines for Culvert Construction to Accommodate Fish and Wildlife Movement and Passage**, Arizona Game and Fish Department, Habitat Branch, November 2006.
www.azgfd.gov/hgis/pdfs/CulvertGuidelinesforWildlifeCrossings.pdf
Design guidance for amphibian and reptile crossings appears on page 8 of this guide. Guidance includes culvert requirements and consideration for opening covers, structure placement, funneling/fencing and internal habitat.

Newer guidance has been developed for Arizona and is provided in David Grandmaison's study, Wildlife Linkage Research in Pima County: Crossing Structures to Reduce Wildlife Mortality (page 27 of this report).

***Wildlife and Roads: A Resource for Mitigating the Effects of Roads on Wildlife Using Wildlife Crossings Such as Overpasses, Underpasses, and Crosswalks**, U.S. Geological Survey, Utah State University and the Transportation Research Board, undated.
http://www.wildlifeandroads.org/
From the web site: This resource can be used to address the issues associated with wildlife corridors, habitat fragmentation, wildlife-vehicle collisions involving deer, elk, moose, bighorn sheep, carnivores, amphibians and reptiles, and small mammals, and other animals, and other road ecology issues.

The web site also includes a search engine for learning about existing and planned wildlife passages in North America, available at http://www.wildlifeandroads.org/search/. The search engine allows searches by species.

This web site is associated with NCHRP project 25-27; see the NCHRP report Evaluation of the Use and Effectiveness of Wildlife Crossings cited in **Herptile Crossing Research: Design, Placement and Evaluation** on page 30.

International Guidance

Australia

***"Making a Safe Leap Forward—Mitigating Road Impacts on Amphibians,"** Andrew Hamer, Tom Langton, David Lesbarrères, *Ecology of Roads: A Practitioner's Guide to Impacts and Solutions*. R. van der Ree, et al. (editors), Wiley Blackwell, in press.

See a discussion of this title in our interviews with Tom Langton and David Lesbarrères on page 10 of this report.

Germany

***Merkblatt zum Amphibienschutz an Straßen (Bulletin on Amphibian Protection on Roadways)**, German Federal Ministry of Transport, Building and Urban Affairs, 2000 (in German; 13.4 MB; available upon request).

From the introduction (translated): This publication contains tools for the planning and design of facilities for protection of amphibians and information on the protection and organization of land and water habitats. This is based on many years of observational research.

Chapter titles include:
- Legal basis.
- Ecological basis.
- Consideration of amphibian conservation in road design and construction.
- Amphibian conservation measures.
- Amphibian protection on existing roads.
- Control and maintenance measures.

***Amphibian and Reptile Conservation News**, Nature and Biodiversity Conservation Union (Germany), undated.
http://www.amphibienschutz.de/schutz/amphibien/amphibienschutz.htm (original)
http://translate.google.com/translate?hl=en&sl=de&u=http://www.amphibienschutz.de/schutz/amphibien/amphibienschutz.htm (translation)
This web page of the Nature and Biodiversity Conservation Union (www.nabu.de/en/index.html) summarizes some of the findings and recommendations in the German bulletin above.

Europe

†Wildlife Habitat Connectivity Across European Highways, International Technology Exchange Program, Federal Highway Administration, August 2002.
http://international.fhwa.dot.gov/Pdfs/wildlife_web.pdf
This report documents wildlife connectivity issues in France, Germany, the Netherlands, Slovenia and Switzerland. A discussion of amphibian and other small-species culverts (pages 12-13 of the report) is excerpted below:

> Amphibian culvert systems were observed in all countries, except Slovenia. Culverts are placed in known areas of amphibian movement to alleviate mortality on roadways. A number of approaches are used. It should be noted that these systems serve the movement of other small animals, as well as amphibians.
>
> Several types of barriers were observed for amphibians. Trenches are used to direct them to culvert structures under the roads. In Switzerland, a one-way system using a pipe for each direction was observed. A concrete trench is used to direct the amphibians to a drop inlet into the pipe leading to the other side. On the wetland side, pipes leading back to the other side are present (figure 10). Grossenbacher (1985) and Ryser (1988) reported that this system was more effective than just single pipes in which the amphibians could move in either direction.
>
> A metal rail type system was observed in Germany to direct reptiles and amphibians to wildlife culverts under Highway B30. In France, a fine mesh plastic material similar to silt screen is used at the bottom of fences to direct smaller animals, including amphibians, to culverts and overpasses. France also was using concrete walls to keep amphibians out of harm's way, but has since stopped using this expensive application.
>
> The Dutch use fine-meshed fence at the bottom of typical highway fences to direct reptiles, amphibians, and small mammals to culvert pipes under their highways. Generally, concrete or metal pipes and rectangular tunnels were observed, with diameters approximately 0.4 to 2.0 m, although larger culvert structures were seen that could accommodate amphibians as well as other wildlife. Figure 11 (page 18) shows several of these applications in Europe.
>
> The Europeans also are modifying curbs and drains to prevent entrapment of reptiles and amphibians. In areas where amphibians are present in large numbers, ramps or breaks in the curb are provided, periodically, to allow exit from the roadway. Mesh screens are used over drainage inlets to keep the amphibians from becoming trapped in pipes.
>
> Underpasses for other small species are similar in design to those used for amphibians. An accepted approach to providing habitat for smaller animals is the placement of rocks, stumps, and other debris in and around structures. In fact, this is becoming a common practice on larger structures, which are discussed next. Another approach used in Europe is providing plant cover around pipes or box culverts for smaller animals.

Herptile Crossing Research: Design, Placement and Evaluation

†"Measures to Reduce Population Fragmentation by Roads: What has Worked and How Do We Know?" David Lesbarrères, Lenore Fahrig, *Trends in Ecology & Evolution*, Vol. 27, No. 7, July 2012: 374-380.
http://www.sciencedirect.com/science/article/pii/S0169534712000341
From the abstract: Roads impede animal movement, which decreases habitat accessibility and reduces gene flow. Ecopassages have been built to mitigate this but there is little research with which to evaluate their effectiveness, owing to the difficulty in accessing results of existing research; the lack of scientific rigor in these studies; and the low priority of connectivity planning in road projects. In this article, the investigators suggest that the imperative for improving studies of ecopassage effectiveness is that road ecology research should be included from the earliest stages of road projects onwards. This would enable before–after–control–impact (BACI) design research, producing useful information for the particular road project as well as rigorous results for use in future road mitigation. Well-designed studies on ecopassage effectiveness could help improve landscape connectivity even with the increasing number and use by traffic of roads.

Further, in Appendix A Caltrans notes: "The authors suggest using extended stream crossings that are about five times the width of the stream at high water with a height over the exposed banks high enough to allow for the passage of the largest animal in the area. They argue that this type of passage will allow connectivity of most animals. Additionally, they assert that 'Overall, extended stream crossings are probably the most cost-effective way of improving connectivity across roads.'"

***"Characterizing Movement Patterns and Spatio-Temporal Use of Under-Road Tunnels by Long-Toed Salamanders in Waterton Lakes National Park, Canada,"** Katie S. Pagnucco, Cynthia A. Paszkowski, Garry J. Scrimgeour, *Copeia*, Vol. 2012, No. 2, June 2012: 331-340.
http://www.asihcopeiaonline.org/doi/abs/10.1643/CE-10-128?journalCode=cope
From the abstract: Linnet Lake (Waterton Lakes National Park, Alberta) is the breeding site of a population of Long-toed Salamanders (*Ambystoma macrodactylum*) that has decreased dramatically over the last 15 years, partially due to vehicle-caused mortality occurring on an adjacent road. In May 2008, Parks Canada installed four amphibian tunnels under this road. Researchers installed drift fences to direct salamanders toward tunnel entrances and monitored tunnel use with pitfall traps in 2008 and 2009. … Salamanders were 20 times more likely to use tunnels when traveling to the breeding site than when leaving the site. Distance from tunnel entrances, sex, and body size did not have significant effects on tunnel use by salamanders. Although salamander movement was positively correlated with occurrence of precipitation, this relationship was much stronger when salamanders were leaving the breeding site. Variation in use between the four tunnels was positively correlated with soil moisture of surrounding habitat.

***Wildlife Linkage Research in Pima County: Crossing Structures and Fencing to Reduce Wildlife Mortality**, David Grandmaison, Arizona Game and Fish Department, 2011.
http://www.rtamobility.com/documents/20111121RTACulvertFencingStudy.PDF
From the executive summary: The research team used standard walking wildlife mortality surveys and video surveillance techniques to document roadkill numbers and quantify culvert use. … We evaluated 4 barrier treatments across a spectrum of common wildlife species among major taxonomic groups in the Sonoran Desert (e.g., amphibians, lizards, snakes, and small mammals). Barrier treatments included concrete panels, concrete panels with a 4 inch overhang, rusticated steel flashing and stacked guard rail. ... Specific recommendations based on this research are provided.

***"Determining Location and Design of Cost Effective Wildlife Crossing Structures Along US 64 in North Carolina,"** Daniel Smith, *Transportation Research Record: Environment 2012*, Issue No. 2270, 2012: 31-38.
http://trid.trb.org/view/2012/C/1130809
From the abstract: [In light of North Carolina DOT's plans to widen U.S. Highway 64] the effects of increased habitat fragmentation and projected sea-level rise were significant concerns. Wildlife surveys were conducted from April 2009 to July 2010 to assess existing highway impacts. Road kill and track surveys provided data on successful and unsuccessful road crossings. Road kill data included 27,877 individuals of 113 species. From 31 track stations, 18 different species or taxa from 7,477 tracks were recorded. Spatial analysis of road kill and track data revealed significant hot spots of wildlife activity. Results of field surveys and landscape analysis were used to determine candidate locations for wildlife crossings and other measures to reduce adverse effects of the proposed widening of the road. Recommendations included type of structure and design specifications according to site specifics and target species requirements.

†Effects of New York State Roadways on Amphibians and Reptiles: A Research and Adaptive Mitigation Program, David A. Patrick, James P. Gibbs, Donald J. Leopold, Peter K. Ducey, Hara W. Woltz, Daniel Crane, Frederic Beaudry, D. Viorel Popescu, Chris Schalk, State University of New York, 2011 (revised).
http://www.utrc2.org/sites/default/files/pubs/effects-nys-roadways-reptiles-final_0.pdf
From the abstract: This report explains the impacts of transportation infrastructure on herptile populations, the landscape, local habitat, and architectural attributes of effective herptile crossing structures and employs habitat analyses to identify "connectivity zones" where crossing structures would be most appropriately deployed along New York State roadways. … Studies focusing on the design of crossing structures have tended to be based either on animals translocated to experimental arenas or monitoring the use of existing structures. The behavior of animals in the former approach may not represent that of animals under natural conditions. To test the effects of culvert attributes, including length, diameter and substrate on choice, researchers applied a novel technique whereby experimental arrays were placed in the path of migrating spotted salamanders, allowing choice to occur under natural movement conditions. A higher abundance of spotted salamanders were found where flowing water was present on the upslope of the road. More American toads were found on sections of road without a wetland on the downslope side and where there was a culvert nearby. Spotted salamanders showed no clear preference for culverts with different attributes. Our results show that predicting where amphibians will be concentrated within crossing hotspots is possible, allowing effective placement of mitigation, but that these patterns are likely to differ between species. We found that spotted salamanders undergoing their natural movements appear to be more tolerant of differences between culverts when compared with studies in experimental arenas, and that a variety of different culverts will work as crossing structures.

Two chapters in particular may be of direct interest to Caltrans: Chapter 5—Road Crossing Structures for Amphibians and Reptiles: Informing Design Through Behavioral Analysis, and Chapter 7—Multi-Scale Habitat-Resistance Models for Predicting Road Mortality "Hotspots" for Reptiles and Amphibians.

†"Identifying Hot Moments in Road-Mortality Risk in Freshwater Turtles," Fredric Beaudry, Phillip G. deMaynadier, Malcolm L. Hunter, Jr., *Journal of Wildlife Management*, Vol. 74, No. 1, January 2010: 152-159.
http://onlinelibrary.wiley.com/doi/10.2193/2008-370/abstract
This research addresses "hot moments" for a species of turtle. *From the abstract:* Risk assessments can be used to identify threats, which vary both in space and time, to declining species. Just as hot spots describe locations where threat processes operate at a higher rate than in surrounding areas, hot moments refer to periods when threat rates are highest. … Blanding's turtle (*Emydoidea blandingii*) populations are potentially most vulnerable to road mortality where road densities and traffic volumes are high. The temporal variations in road-mortality risk faced by these and other semiaquatic turtles at the population

level are a consequence of several factors, including sex-specific movement characteristics and seasonal changes in traffic volume. Researchers examined these risk factors for Blanding's turtle populations in Maine, USA, by integrating temporally explicit roadkill probabilities with demographic parameters informed by local and range-wide studies.

Caltrans further notes in Appendix A: "The approach used in this study can be modified for use with species in California."

†"Effective Culvert Placement and Design to Facilitate Passage of Amphibians Across Roads," David A. Patrick, Christopher M. Schalk, James P. Gibbs, Hara W. Woltz, *Journal of Herpetology*, Vol. 44, No. 4, 2010: 618-626.
http://www.savethefrogs.com/actions/roads/images/Patrick-2010-Culvert-Roads.pdf
From the abstract: Efficient deployment of culverts to mitigate mortality of amphibians on roadways requires identification of locations within road networks where animals cross (hotspots), points within identified hotspots for culvert placement, and attributes of culverts that make them behaviorally palatable to migrating individuals. In this study, researchers assessed road crossing frequency of Spotted Salamanders, *Ambystoma maculatum*, and American Toads, *Anaxyrus americanus*, along a 700-m transect within a known crossing hotspot, and related these distributions to habitat variables within the hotspot including the presence of existing culverts. Researchers also placed experimental arrays of culverts of varying attributes in the path of migrating Spotted Salamanders to examine culvert preference by salamanders under typical movement environments and appropriate animal behavioral states. Studies of patterns of road occurrence demonstrated that both species avoided crossing where there was a wetland within 15 m of the downslope of the road and that neither species showed a strong preference for crossing near existing culverts. When considering the choice for experimental culverts by Spotted Salamanders, researchers found no preference for culverts of varying aperture size, length, or substrate. Results indicate that patterns of occurrences of the two species of amphibian within a crossing hotspot may be linked to the physical attributes at the site. For Spotted Salamanders in particular, predicting where they will cross within a hotspot may not be easy. Spotted Salamanders showed little preference for culverts of different design, indicating that a variety of culvert designs can suffice for mitigation if placed in appropriate locations.

†"Predicting Hot Spots of Herpetofauna Road Mortality along Highway Networks," Tom A. Langen, Kimberly M. Ogden, Lindsay L. Schwarting, *Journal of Wildlife Management*, Vol. 73, No. 1, 2009: 104-114.
http://www.bioone.org/doi/abs/10.2193/2008-017?journalCode=wild
From the abstract: Road mortality is often spatially aggregated, and there is a need for models that accurately and efficiently predict hot spots within a road network for mitigation. We surveyed 145 points throughout a 353-km highway network in New York State, USA, for roadkill of reptiles and amphibians. We used land cover, wetland configuration, and traffic volume data to identify features that best predicted hot spots of herpetofauna road mortality. … Both amphibian and reptile road mortality were spatially clustered, and road-kill hot spots of the 2 taxa overlapped. … We conclude it is possible to identify valid predictors of hot spots of amphibian and reptile road mortality for use when planning roads or when conducting surveys on existing roads to locate priority areas for mitigation.

Caltrans further notes in Appendix A: "For the purposes of application in California the most important aspect of this paper is the stepwise methodology for herptile mitigation measures. First, determine the spatial pattern of mortality based on valid survey data using valid survey methodologies. Second, determine landscape, road, or traffic pattern features that are correlated with the locations of high mortality in multiple locations. Third, create a protocol that can be applied by practitioners to identify mortality hotspots and hence potential locations for mitigation measures."

†"A Review of Mitigation Measures for Reducing Wildlife Mortality on Roadways," David J. Glista, Travis L. DeVault, J. Andrew DeWoody, *Landscape and Urban Planning*, No. 91, 2009: 1-7.
http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1842&context=icwdm_usdanwrc
From the abstract: [The authors] briefly review wildlife-crossing structures, summarize previous wildlife road mortality mitigation studies, describe common mitigation measures, and discuss factors that influence the overall effectiveness of mitigation strategies.

***Wildlife Crossings: The State of the Science—A Literature Review**, Creative Resource Strategies, LLC, September 2008.
http://www.createstrat.com/i/wildlifecrossings.pdf
This report, prepared for the city of Portland, OR, presents an extensive annotated literature search on wildlife mitigation measures. Vicki Sharpe of Florida DOT described the report as a very helpful publication that integrates all aspects of the practice, including planning and funding. Subtopics include the ecological impacts of roads, roadkill mitigation, crossing measures, monitoring and funding. Design considerations for amphibians are summarized on page 34.

***Evaluation of the Use and Effectiveness of Wildlife Crossings**, John A. Bissonette, Patricia C. Cramer, *NCHRP Report 615*, 2008.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_615.pdf
From the abstract: This report documents the development of an interactive, web-based decision guide protocol for the selection, configuration, and location of wildlife crossings. … Transportation planners and designers and wildlife ecologists have access to clearly written, structured guidelines to help reduce loss of property and life due to wildlife–vehicle collisions, while protecting wildlife and their habitat. The guidelines were based on goals and needs identified and prioritized by transportation professionals from across North America, and developed using the results of five parallel scientific studies.

Hotspots modeling for different species and landscapes (including California)
In Section 3.3 of this report, "Hotspots Modeling" (page 62), the research team investigates various clustering techniques to identify wildlife-vehicle collision hotspots in a variety of landscapes, taking into account different scales of application and transportation management concerns (for example, motorist safety and endangered species management).

Researchers studied two areas to "describe the hotspot patterns/configurations and examine how they may differ by species and ... landscape types." The terrain will be of interest to Caltrans: One study was set in Sierra County, CA, in the Sierra Nevada Mountains; the other was in the central Canadian Rocky Mountains in western Alberta. A discussion titled "Hotspot Identification and Patterns for Different Species and Landscapes" for the two areas studied begins on page 73.

Small animals
While this report does not focus on herptiles, some of the methodologies described for studying small mammals (Section 3.4, Influence of Roads on Small Mammals, page 76) might be applicable to herptiles. For example, both herptiles and small mammals may have in common relatively small home ranges and limited mobility (page 77).

Web site
The online decision guide developed through this research is available at http://www.wildlifeandroads.org/decisionguide/.

†"Effectiveness of a Barrier Wall and Culverts in Reducing Wildlife Mortality on a Heavily Traveled Highway in Florida," C. Kenneth Dodd, Jr., William J. Barichivicha, Lora L. Smith, *Biological Convservation*, Vol. 118, No. 5, August 2004: 619-631.
http://www.sciencedirect.com/science/article/pii/S0006320703004087
This is the follow-up research on the Paynes Prairie ecopassage in Florida, as we discussed with Ken Dodd in **Expert Interviews**.

†"What Type of Amphibian Tunnel Could Reduce Road Kills?" David Lesbarrères, Thierry Lodé, Juha Merilä, *Oryx*, Vol. 38, No. 2, April 2004: 220-223.
http://www.helsinki.fi/biosci/egru/pdf/2004/Oryx2004.pdf
From the abstract: Increased traffic volumes worldwide are contributing to amphibian declines, and measures to reduce the occurrence of road kills are needed. One possible measure is the construction of underpasses through which animals can pass under roads, but little is known about whether amphibians will choose tunnels if given a choice or about their preferences for different tunnel types. Researchers tested the preferences of three anuran species for two kinds of concrete amphibian tunnels currently used in France. One was a tunnel lined with soil, the other a bare concrete pipe. The animals could use the tunnels or bypass them over a grassy area. Water frogs *Rana esculenta* and common toads *Bufo bufo* showed a preference for the tunnels, whereas agile frogs *Rana dalmatina* avoided them. Among the individuals that chose either of the tunnels, all species showed a significant preference for the tunnel lined with soil. These results indicate that species differ in their preferences and in their likelihood of using underpasses when given a choice. This highlights the fact that there is no unique solution to the problem, and underpasses are only one of the possible mitigation measures that need to be assessed.

***"An Overview of Methods and Approaches for Evaluating the Effectiveness of Wildlife Crossing Structures: Emphasizing the Science in Applied Science,"** Amanda Hardy, Anthony P. Clevenger, Marcel Huijser, Graham Neale, *Proceedings of the 2003 International Conference on Ecology and Transportation*, August 2003: 319-330.
http://escholarship.org/uc/item/8gj3x1dc.pdf
From the abstract: We review past and current methods used to evaluate wildlife crossing structures and examine criteria to consider when evaluating wildlife passage effectiveness. We focus on methods to monitor mammals and summarize representative studies published [in] international journals and conference proceedings.

***Wildlife Use and Interactions with Structures Constructed to Minimize Vehicle Collisions and Animal Mortality along State Road 46, Lake County, Florida**, Gregg Walker, Jo Anna Barber, Florida Department of Environmental Protection, October 2003.
http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_EMO/FDOT_BD162_rpt.pdf
A box culvert and fencing system, originally installed to protect a threatened bear species, was evaluated to determine effectiveness in preventing roadkill for a range of animals. Data showed that fencing reduced the number of roadkills within the fence limits, especially for mammals. Researchers noted that small mammals, reptiles and amphibians were able to move either under or through the fence. They also recommended exploring additional fencing options.

***Monitoring Wildlife Use and Determining Standards for Culvert Design**, Daniel J. Smith, Florida Department of Transportation, October 2003.
http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_EMO/FDOT_BC354_34_rpt.pdf
This report "provides an approach to classification of drainage culverts and bridges based on structural characteristics and suitability of use by various wildlife taxa." It discusses in detail herptiles' use of bridges (page 49) and culverts (page 53).

†**Proposed Design and Considerations for Use of Amphibian and Reptile Tunnels in New England**, Scott Jackson, University of Massachusetts Amherst, 2003.
http://www.centrostudiarcadia.it/Herp_Tunnels.pdf
This paper presents underpass designs for facilitating overland passage of amphibians and reptiles. It also provides questions to consider when determining if herptile passages are appropriate or recommended.

*****Interaction Between Roadways and Wildlife Ecology: A Synthesis of Highway Practice**, Gary Evink, *NCHRP Synthesis 305*, 2002.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_305.pdf
Chapter 7—Conservation Measures and Mitigation (page 29) discusses a number of mitigation features. Structural techniques described in detail include fencing, drainage culverts, stream culverts and bridges, underpass bridges and dry culverts, extended bridges, viaducts and overpasses. For each, relative cost and appropriateness for different species—including reptiles and amphibians—is discussed. Beyond structural techniques, the chapter also describes mitigation measures of habitat techniques and programmatic agreements.

***Reducing Impacts on Rare Vertebrates that Require Small Isolated Water Bodies along U.S. Highway 319**, D. Bruce Means, Florida Department of Transportation, September 30, 2001.
http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_EMO/BB278_rpt.pdf
This is the premonitoring study for the herptile crossing on Highway 319 as discussed with Vicki Sharpe in **Expert Interviews**.

Herptile Road Ecology

***"Do Species Life History Traits Explain Population Responses to Roads? A Meta-Analysis,"** Trina Rytwinski, Lenore Fahrig, *Biological Conservation*, Vol. 147, No. 1, March 2012: 87-98.
http://www.sciencedirect.com/science/article/pii/S0006320711004411
We discussed this meta-analysis with Lenore Fahrig in **Expert Interviews**.

†"Contrasting Road Effect Signals in Reproduction of Long- Versus Short-Lived Amphibians," Nancy E. Karraker, James P. Gibbs, *Hydrobiologia*, Vol. 664, 2011: 213-218.
http://www.springerlink.com/content/4k0vt284516125r7/fulltext.pdf
Like our discussion of reproduction potential with Sandra Jacobson (see **Expert Interviews**, page 16), this paper addresses amphibian species lifespan and road mortality. *From the abstract:* We predicted that road mortality could exert a disproportionate effect on fecundity in long-lived species due to shifts in population age structures to younger individuals of smaller size that produce commensurately smaller egg masses. To test this hypothesis, researchers assessed egg mass sizes of a long-lived amphibian (spotted salamander, *Ambystoma maculatum*) and short-lived one (wood frog, *Rana sylvatica*) in wetlands near and far from highways. Egg mass sizes of *A. maculatum* were smaller in wetlands near highways. In contrast, those of *R. sylvatica* were similar among wetlands regardless of the distance from highways. Researchers concluded that paved highways with moderate traffic volume may be having important effects on populations of long-lived amphibians through mortality-mediated depression of reproduction.

†"Quantifying the Road-Effect Zone: Threshold Effects of a Motorway on Anuran Populations in Ontario, Canada," Felix Eigenbrod, Stephen J. Hecnar, Lenore Fahrig, *Ecology and Society*, Vol. 14, No. 1, Article 24, 2009.
http://www.ecologyandsociety.org/vol14/iss1/art24/
From the abstract: The "road-effect zone," i.e., the extent of significant ecological effects from the edge of a road, has important management implications but has never been quantified for anurans. In the first study of its kind, we measured the extent and type of relationship underlying the road-effect zones of a motorway with a high proportion of heavy-truck traffic, particularly at night (Highway 401) for anuran species richness and relative abundance. … Results show that most anurans are likely to have reduced

abundances near motorways, but that both the extent of the effect of this type of road and the underlying relationship vary considerably between species. Furthermore, the noise and/or barrier effect of very high nighttime traffic volumes can lead to negative effects of motorways even on species that are relatively unaffected by direct road mortality.

†**"Vertebrate Road Mortality Predominantly Impacts Amphibians,"** David J. Glista, Travis L. DeVault, J. Andrew DeWoody, *Herpetological Conservation and Biology*, Vol. 3, No. 1, 2008: 77-87. http://www.savethefrogs.co.uk/actions/roads/images/Glista%202007%20Roadkill%20Mortality%20in%20Amphibians.pdf
From the abstract: Most studies of road-kill have focused on large mammals, but relatively little research has evaluated the impact of road-kill on other wild animals. We conducted multi-species road-kill surveys in Indiana, USA to develop a road-kill database and to identify habitat characteristics associated with road-kill. Four different routes were surveyed for vertebrate mortalities twice weekly from 8 March 2005 to 31 July 2006. … Habitat variables that best predicted vertebrate mortality were water, forest, and urban/residential areas. Overall, our results suggested that road mortality impacts a wide variety of species and that habitat type strongly influences frequency of road-kill. Amphibians may be especially vulnerable because they often migrate *en masse* to or from breeding wetlands. Clearly, road-kill is a major source of amphibian mortality and may contribute to their global decline.

†**"The Rauischholzhausen Agenda for Road Ecology,"** Inga A. Roedenbeck, Lenore Fahrig, C. Scott Findlay, Jeff E. Houlahan, Jochen A. G. Jaeger, Nina Klar, Stephanie Kramer-Schadt, Edgar A. van der Grift, *Ecology and Society*, Vol. 12, No. 1, Article 11, 2007.
http://www.ecologyandsociety.org/vol12/iss1/art11/
From the abstract: We argue that road research would have a larger impact if researchers carefully considered the relevance of the research questions addressed and the inferential strength of the studies undertaken. At a workshop at the German castle of Rauischholzhausen we identified five particularly relevant questions, which we suggest provide the framework for a research agenda for road ecology: (1) Under what circumstances do roads affect population persistence? (2) What is the relative importance of road effects vs. other effects on population persistence? (3) Under what circumstances can road effects be mitigated? (4) What is the relative importance of the different mechanisms by which roads affect population persistence? (5) Under what circumstances do road networks affect population persistence at the landscape scale? We recommend experimental designs that maximize inferential strength, given existing constraints, and we provide hypothetical examples of such experiments for each of the five research questions.

Road Ecology of California Species

†**"Fine-Scale Analysis Reveals Cryptic Landscape Genetic Structure in Desert Tortoises,"** Emily K. Latch, William I. Boarman, Andrew Walde, Robert C. Fleischer, *PLoS ONE*, Vol. 6, No. 11, 2011: e27794.
http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0027794
From the abstract: We investigated fine-scale spatial patterns of genetic variation and gene flow in relation to features of the landscape in desert tortoise (*Gopherus agassizii*), using 859 tortoises genotyped at 16 microsatellite loci with associated data on geographic location, sex, elevation, slope, and soil type, and spatial relationship to putative barriers (power lines, roads). … Desert tortoises exhibit weak genetic structure at a local scale, and we identified two subpopulations across the study area. Although genetic differentiation between the subpopulations was low, landscape genetic analysis identified both natural (slope) and anthropogenic (roads) landscape variables that have significantly influenced gene flow within this local population. We show that desert tortoise movements at a local scale are influenced by features of the landscape, and that these features are different than those that influence gene flow at larger scales.

†**"Turtles and Culverts, and Alternative Energy Development: An Unreported But Potentially Significant Mortality Threat to the Desert Tortoise (*Gopherus agassizii*),"** Jeffrey E. Lovich, Joshua R. Ennen, Sheila Madrak, Bret Grover, *Chelonian Conservation and Biology*, Vol. 10, No. 1, July 2011: 124-129.
http://www.chelonianjournals.org/doi/abs/10.2744/CCB-0864.1
From the abstract: Although the benefits of culverts as safe passages for turtles are well documented, under some conditions culverts can entrap them and cause mortality. Here we report a culvert-related mortality in the federally threatened desert tortoise (*Gopherus agassizii*) at a wind energy facility in California and offer simple recommendations to mitigate the negative effects of culverts for wildlife in general.

Caltrans further notes in Appendix A: "This paper reports on the mortality of a listed desert tortoise in southern California by entombment of a hibernating tortoise by silt entering and filling a corrugated steel culvert about 60 cm in diameter during rainstorms. The authors suggest that larger diameter culverts with a diameter of 1 meter or greater should be used in desert tortoise habitat. Alternatively, tortoise excluders may be installed on smaller culverts, but care must be taken to prevent tortoises from going up onto road surfaces."

†**SPR-650, Predicting Desert Tortoise (*Gopherus agassizii*) Habitat and Identifying Movement Patterns within the Proposed Highway 95 Realignment**, Arizona Department of Transportation, research in progress, 2012: 27.
http://www.azdot.gov/TPD/ATRC/publications/SPR/SPR_book_2012.pdf
We discussed this research with investigator David Grandmaison in **Expert Interviews**. The research objectives of this project are to:

- Develop and validate a soil-based predictive model for desert tortoise occupancy to quantify potential impacts from proposed SR 95, and to recommend specific placement of the alignment.
- Using GPS tracking devices, identify areas along the proposed SR 95 realignment for the potential placement of underpass structures to facilitate safe tortoise passage.
- Determine effectiveness of existing crossing structures and associated fencing constructed to facilitate the crossing of desert tortoises on Highway 93.
- Provide recommendations for improvement and assess feasibility of similar mitigation for proposed Highway 95 project in the Black Mountain area.

†**"The Negative Effects of Barrier Fencing on the Desert Tortoise (*Gopherus agassizii*) and Non-Target Species: Is There Room for Improvement?"** Joseph S. Wilson, Seth Topham, *Contemporary Herpetology*, Vol. 2009, No. 3, December 26, 2009: 1-4.
http://www.naherpetology.org/pdf_files/1404.pdf
From the abstract: Barrier fences have been installed along roadsides in many parts of the Mojave Desert to protect the threatened Desert Tortoise (*Gopherus agassizii*) and other wildlife species from being killed by vehicles. Some species, occasionally including the desert tortoise, manage to get across the barrier fences and, if not killed by collision with a vehicle, remain trapped in the small shoulder area next to the roads. We report several observations made in the Red Cliffs Desert Reserve near St. George, Utah, of reptiles that had been trapped by barrier fences. We make suggestions on how to improve the current design of tortoise barrier fences to avoid accidental entrapment and death.

Aquatic Wildlife

***Design of Road Culverts for Fish Passage**, Washington Department of Fish and Wildlife, 2003.
http://wdfw.wa.gov/publications/00049/wdfw00049.pdf
Although this reference deals with road crossings for fish, it is noted that "[w]ildlife passage under roads can be provided with large stream-simulation culverts. … Amphibians and small animals likely can pass on the banks inside" (page 32).

Additional Web Resources

***Directory of State Highway Agency and Federal Highway Administration Environmental Officials**, Transportation Research Board, 2012.
http://www.itre.ncsu.edu/ADC10/docs/Directory_of_SHA_and_Env_Officials.pdf
This directory provides a comprehensive list of state DOT staff involved with environmental issues. It includes titles and contact information where available. The guide lists information for FHWA's Office of Planning, Environment & Realty; FHWA Resource Center's Environment Technical Service Team; and FHWA division offices.

***The Herpetologists' League**
http://www.herpetologistsleague.org/en/
From the web site: The Herpetologists' League, established in 1946, is an international organization of people devoted to studying herpetology—the biology of amphibians and reptiles. HL publishes two scholarly journals—the quarterly Herpetologica, which contains original research papers and essays, and the annual supplement Herpetological Monographs, which contains lengthy research articles, syntheses, and special symposia.

***Society for the Study of Amphibians and Reptiles**
http://www.ssarherps.org
From the web site: [Society for the Study of Amphibians and Reptiles (SSAR)], a not-for-profit organization established to advance research, conservation, and education concerning amphibians and reptiles, was founded in 1958. It is the largest international herpetological society, and is recognized worldwide for having the most diverse program of publications, meetings, and other activities.

SSAR publications include the *Journal of Herpetology*, a peer-reviewed scientific journal published quarterly, and *Herpetological Review*, a peer-reviewed quarterly that publishes articles and notes of a semitechnical or nontechnical nature.

***American Society of Ichthyologists and Herpetologists**
http://www.asih.org
From the web site: The American Society of Ichthyologists and Herpetologists is dedicated to the scientific study of fishes, amphibians and reptiles. The primary emphases of the Society are to increase knowledge about these organisms, to disseminate that knowledge through publications, conferences, symposia, and other means, and to encourage and support young scientists who will make future advances in these fields.

The society produces a quarterly journal, *Coepia*, that publishes original research about fishes, amphibians and reptiles, with an emphasis on systematics, ecology, behavior, genetics, morphology and physiology.

***World Congress of Herpetology**
http://www.worldcongressofherpetology.org
From the web site: The objectives of the Congress are to promote international interest, collaboration and co-operation in herpetology. These are to be achieved by holding periodic international congresses of herpetology, by establishing specialist committees, by serving as the Section of Herpetology of the International Union of Biological Sciences and by undertaking or encouraging such other activities as will promote these objectives.

The World Congress of Herpetology (WCH) meets every three to five years, most recently in Vancouver, British Columbia, Canada, in August 2012. The next WCH will be held in Hagzhou, China, in August 2016.

Appendix A

Annotated Literature for Promoting the Ability of Sensitive Reptiles and Amphibians to Cross Highways

A

Allaback, Mark L. and David M. Laabs. 2003. Effectivness of road tunnels for the Santa Cruz long-toed salamander. Transactions of the Western Section of the Wildlife Society 38/39: 5-8.

Complete Paper

These authors examined the efficacy of a combination tunnels and drift fences on *Ambystoma macrodactylum croceum* in the Seascape Uplands residential development of Aptos, CA. They concluded that use of the tunnels was relatively low and that the system of drift fences and tunnels nay not be an effective mitigation approach for this species in this location.

Andrews, K. M. 2003. Behavioral responses of snakes to road encounters: Can we generalize impacts across species? (A preliminary overview). 649–651. *In:* Proceedings of the International Conference on Ecology and Transportation. C.L. Irwin, P. Garrett, and K.P. McDermott (eds.). Center for Transportation and the Environment, North Carolina State Univ., North Carolina.

Availability: Complete Document

Andrews performed 846 behavioral experiments with 27 species of southeastern snakes at the Savannah River Site, Aiken SC. This was presented at ICOET while the research was still in progress. However, at this point she stated that the behavior of snakes in relation to roads and vehicles was species dependent and could not be generalized. This was the pilot for the study detailed and reported in Andrews and Gibbons 2005 below.

Andrews K. M., Gibbons J. W. 2005. How do highways influence snake movement? Behavioral responses to roads and vehicles. Copeia 2005:772–782.

Availability: Complete Document

and

Andrews Kimberly M., and J. W. Gibbons. 2006. Dissimilarities in behavioral responses of snakes to roads and vehicles have implications for differential impacts across species p. 339-350. In Proceedings of the 2005 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Availability Complete document. This paper is posted at the eScholarship Repository, University of California. http://repositories.cdlib.org/jmie/roadeco/Andrews2005a

This paper and ICOET presentation report the refined version of the study Andrews 2003 above. From the 27 original species the authors chose a group of nine southeastern snake species for detailed analysis. Crossing speeds and angles from Andrews 2003 were used. All other measurements and observations were newly made. Two aspects of snake behavior were observed: the response to encountering a road; and the response to a passing vehicle. The crossing probabilities, speed of crossing, and angle of crossing were noted for the nine species. Three species (North American Racer, Eastern Ratsnake, and Timber Rattlesnake) were studied for behavior related to passing vehicles. Temperature (air, ground, and roadway), humidity, barometric pressure, rainfall, cloud cover, and wind strength were measured. Species avoided the road differentially (smaller species tended to avoid the road more), and the road crossing speed also differed greatly by species (long slender species tended to cross more quickly than stouter species; nonvenomous species tended to cross faster than venomous species), however all species crossing the road tended to cross it perpendicularly. All tested species exhibited immobilization in response to vehicles particularly when the vehicles passed close by.

Andrews K. M., Gibbons J. W. 2008. Roads as catalysts of urbanization: snakes on roads face differential impacts due to inter- and intraspecific ecological attributes p.145-153. *In:* Mitchell J. C., Jung Brown R. E., Bartholomew B., editors. Urban Herpetology. Salt Lake City, Utah: Society for the Study of Amphibians and Reptiles.

Availability: Complete Document

Note: This work was partially funded by FHWA

The authors examined 15,697 records of 35 species of native snakes collected from 1951-2005 at the U. S. Department of Energy Savannah River Site in South Carolina. They examined inter and intra specific differences in sex and survival status of on-road captures. Additionally they examined the species richness, sex, and body size differences between on-road and off-road records. The main findings of the study included: drive-by examinations of roads cannot be used to assess the diversity and abundance of snake populations, unlike turtles males are overrepresented in the samples of snakes found on roads, and within some species larger individuals are more prevalent in road samples than smaller individuals.

Andrews, K. M., J. W. Gibbons, and D. M. Jochimsen. 2008. Ecological effects of roads on amphibians and reptiles: a literature review, p 121- 143. *In* J. C. Mitchell and R. E. Jung (eds.), Urban Herpetology. Society for the Study of Amphibians and Reptiles, Herpetological Conservation Volume 3, Salt Lake City, UT.

Availability: Complete Chapter

This is a major recent literature review on the impacts of roads on herptiles. According to the authors the objectives of this book chapter are to: identify the biological characteristics of the herpetofauna that make them particularly susceptible to negative impacts from roads; discuss how roads impact individual herptilts, herptiles populations, and herptile communities; provide examples of mitigation and planning solutions for road impacts to herptiles. This redaction was supported by funding from the FHWA.

Andrews et al. 2008 is a redaction of:

Andrews, Kimberly M., J. Whitfield Gibbons, and Denim M. Jochimsen. 2006. Literature synthesis of the effects of roads and vehicles on amphibians and reptiles. Final Draft. Federal highway Administration. McClean, VA. 150 pp.

Availability: Complete Report

This information was also presented in poster form in the ICOET 2007 conference as:

Andrews, Kimberly; J. Whitfield Gibbons, and Denim M. Jochimsen. 2007. Ecological effects of roads infrastructure on herpetofauna: understanding biology and increasing communication. In Proceedings of the 2007 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Debra Nelson, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2007.pp 567-582.

Complete Document

http://repositories.cdlib.org/jmie/roadeco/Andrews2007b

Aresco, Matthew J. 2005a. The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. Biological Conservation 123: 37-44.

Complete Paper

Note: See Aresco 2005b for information on the study area.

Aresco studied the sex ratio of four turtles - Florida Cooter (*Pseudemys floridana*)[now classified as a subspecies of *P. concinna* by some], Yellow-bellied Slider (*Trachemys scripta scripta*), Eastern Mud Turtle (*Kinosternon subrubrum*), and Florida Softshell (*Apalone ferox*) – at Lake Jackson, FL bisected by U. S. Route 27 as compared to populations in three ponds remote from roads. The ratio in the lake was determined by counting turtles during a mass migration event precipitated by drought. All turtles were collected from the ponds. He determined that all species except for the highly aquatic softshell had male biased populations in Jackson Lake as compared to the populations in the ponds. During average rainfall years females of all four species were significantly more likely to exhibit terrestrial movements than males probably due to nesting. Aresco determined that the male sex bias in the lake is likely due to increased road mortality of the females as they travel on land. The preponderance of female mortality may increase the potential for extinction in K selected species such as turtles.

Aresco, Matthew J. 2005b. Mitigation measures to reduce highway mortality of turtles at a North Florida lake. Journal of Wildlife Management 69(2): 549-560.

Complete Paper

and

Aresco, Matthew J. 2003. Highway mortality of turtles and other herpetofauna at Lake Jackson, Florida, USA and the efficacy of a temporary fence/culvert system to reduce roadkills p. 433- 449. *In* ICOET 2003 Proceedings.

Availability: Complete Paper in ICOET 2003 Herpetiles.

This paper discusses the apparently successful use of temporary fencing and an existing culvert to facilitate travel between two adjacent lakes across U. S. 27 a four lane divided highway and reduce turtle mortality. The temporary fencing was built from woven vinyl erosion control fencing and pre-attached wooden stakes. The bottom of the fencing was buried around 20 cm deep in the soil. The top of the fence was about 0.4 m above ground level. This fence was designed to be a drift fence to direct turtles to a culvert. The culvert was 3.5 m in diameter. During the warm season the fence was monitored four times a day during 2000 and 2001 and twice a day during 2002 and 2003. From November to February the fence was monitored once a day except when the high temperature was below 14°C when monitoring was omitted. The author recommends very frequent monitoring of fences to insure the fence's integrity and to rescue any animals that have gone around the fence. The total fence monitoring effort was 5,664 hours over 1,367 days. The number of turtles found dead on the road was significantly reduced after installation of the fence.

B

Bank, Fred G.; C. Leroy Irwin, Gary L. Evink, Mary E. Gray, Susan Hagood, John R. Kinar, Alex Levy, Dale Paulson, Bill Ruediger, Raymond M. Sauvajot, David J. Scott, Patricia White 2002. Wildlife Habitat Connectivity Across European Highways. Federal Highway Administration, Washington D.C.

Availability: Complete Document

This document provides a broad overview of amphibian road crossings in Europe.

Beasley, Barbara. 2006. A study on the incidence of amphibian mortality between Ucluelet and Tofino, British Columbia. Wildlife Afield 3(1 Supplement): 23-28.

Availability: Complete Document

Beasley discusses a geographical amphibian mortality hotspot on Vancouver Island. She notes where amphibian tunnels existed in BC at the time of writing and briefly discusses trapping and moving amphibians across roads.

Beaudry, Fredric; deMaynadier Phillip G., and Hunter Malcolm L. Jr. 2008. Identifying road mortality threat at multiple spatial scales for semi-aquatic turtles. Biological Conservation 141: 2550-2563.

Availability: Complete Document

The authors develop modeling approaches for spotted turtles (*Clemmys guttata*) and Blanding's turtles (*Emydoidea blandingii*) at the single movement, road segment, and population scales to determine spatial mortality hot-spots on roads in Maine. Spatial hotspots were evident at the road segment level. The approach used in this study can be modified for use with species in California.

Beaudry Fredric, deMaynadier Phillip G., and Hunter Malcolm L. Jr. 2010. Identifying hot moments in road-mortality risk in freshwater turtles. Journal of Wildlife Management 74(1): 152-159.

Availability: Complete Document

The authors develop a modeling approach for Blanding's turtles (*Emydoidea blandingii*) to determine temporal mortality "hot moments" on roads in Maine. The approach used in this study can be modified for use with species in California.

Boarman, W. I. and M. Sazaki M. 2006. A highway's road-efect zone for desert tortoises (*Gopherus agassizii*). Journal of Arid Environments 65 (1): 94-101.

Availability: Abstract Only

The authors detected depressed populations of desert tortoises in the Mojave Desert to at least 400 m from roadways. They suspect road mortality as the cause of the population depression. Depressed populations along roadways may reduce the efficacy of road crossings built for herptiles.

Boarman, William I. and Marc Sazaki. 1996. Highway mortality in desert tortoises and small vertebrates: success of barrier fences and culverts p. 169-173. *In* Evink, Gary; David Ziegler, Paul Garrett, and Jon Berry. Highways and movement of wildlife: improving habitat connections and wildlife passageways across highway corridors. Proceedings of the Florida Department of Transportation/Federal Highway Administration transportation-related wildlife mortality seminar.

and

Boarman, William. I., Marc Sazaki, and W. Bryan Jennings. 1997. The effect of roads, barrier fences, and culverts on desert tortoise populations in California, USA. Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles – an International Conference pp. 54-58. New York Turtle and Tortoise Society.

Availability: Complete Paper

and

Boarman, William I., Michael L. Beigel, Glenn C. Goodlet, and Marc Sazaki. 1998. A passive integrated transponder for tracking animal movements. Wildlife Society Bulletin 26(4): 886-891.

and

Boarman, W.I., and Kristan, W.B., 2006, Evaluation of evidence supporting the effectiveness of desert tortoise recovery actions: U.S. Geological Survey Scientific Investigations Report 2006–5143, 27 p.

Availability: Complete Report

Boarman, Sazaki, and others did extensive work on the efficacy of a fence and culvert system constructed by Caltrans in 1990 to facilitate the movement of desert tortoises across SR 58 east of Kramer Junction. The road was 4 lanes divided and had an ADT around 8500. The fence was 24 km long consisting of 60 cm wide 1.3 cm mesh galvanized steel hardware cloth buried 15 cm and extending 45 cm above the ground. Above the hardware cloth was a six wire strand (the top three strands barbed). The bottom two un-barbed strands are below the top of the hardware cloth to provide support for the fence. 2 m t-bars spaced ca. 3 m apart were used to support the fence. The fence was funneled to 24 culverts both steel and concrete. A 1.6 km^2 study plot was established about 11 km east of Kramer Junction. There appeared to be a significant reduction of tortoise mortality when the fence was properly maintained. Some tortoises did cross the highway via the culverts.

C

Carr, Laurie and Lenore Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. Conservation Biology 15 (4) 1071-1078.
Complete Document

Crother, B. I. (ed.). 2008. Scientific and Standard English Names of Amphibians and Reptiles of North America North of Mexico, pp. 1–84. SSAR Herpetological Circular 37.
Complete Book

Clark, Rulon W., William S. Brown, Randy Stechert, and Kelly Zamudio. 2010. Roads, interrupted dispersal, and genetic diversity in timber rattlesnakes. Conservation Biology 24 (4): 1059-1069.
Availability: Complete Document
Note: New York

Coffin, Alisa W. 2007. From roadkill to road ecology: a review of the ecological effects of roads. Journal of Transport Geography 15: 396-406.
Availability: Complete Document
A succinct review of the ecological impacts of roads.

Cushman, Samuel A. 2006. Effects of habitat loss and fragmentation on amphibians: a review and prospectus. Biological Conservation 128: 231-240.
Complete Document
Asserts that low vagility amphibians are also prone to extinction due to habitat fragmentation.

D

Dodd C. Kenneth Jr., William J. Barichivich, and Lora L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118: 619-631.
Complete Paper

The researchers studied the effectiveness of a highway crossing mitigation system constructed for U. S. Route 441 where it crosses Paynes Prairie State Preserve, Alachua County, Florida to reduce the amount of mortality from wildlife vehicle collisions and provide wildlife connectivity across the highway. The crossing mitigation system consisted of a 1.1 m high concrete wall on each side of the highway with a length of around 2.5 km. The top of the wall had a 15.2 cm overhang. Two partially submerged 2.4m X 2.4 m X 44 m partially submerged box culverts, two usually dry 1.8 m X 1.8 m X 44 m box culverts, and four cylindrical 0.9 m in diameter X 44 m cylindrical culverts were installed along the roadway. In the northwest portion of the study area about 300 m of hardware cloth fencing was installed in lieu of the concrete wall to improve potential drainage. The authors measured post-construction mortality and culvert use and compared the results the post construction to pre construction measurements. The authors

concluded that despite the problems associated with interpretation of their data that mortality was decreased and the use of culverts by wildlife increased. They utilized the six criteria developed in Forman et al, (2003). During the 12 months prior to construction 2411 road killed animals were reported in the study area, while 158 road killed animals were reported after construction. Hylid mortality increased somewhat over preconstruction rates, but other species showed a decline in mortality. The use of culverts also has appeared to have increased after construction. The hardware cloth fence appeared to be ineffective in preventing animals from accessing the roadway surface. The researchers recommend regular maintenance for vegetation control, for insuring the integrity of the fencing, and for removing silt from the culverts.
Note: Smith and Dodd 2003 below reports pre construction mortality for this study.

Dunning, John B., Brent J. Danielson, and H. Ronald Pulliam. 1992. Ecological processes that affect populations in complex landscapes. Oikos 65(1): 169-175.
Complete Paper

E

Eigenbrod, F., S. J. Hecnar, and L. Fahrig. 2009. Quantifying the road-effect zone: threshold effects of a motorway on anuran populations in Ontario, Canada. Ecology and Society 14(1): 24. [online].
Complete Paper

Elliot, Lang; Carl Gerhardt and Carlos Davidson. 2009. The frogs and toads of North America: a comprehensive guide to their identification, behavior and calls. Houghton, Mifflin, Harcourt, New York. 343 pages plus a CD of calls.
Book Print Library
Note: This work contains old and new scientific names and photos.

Ervin E. L. , R. N. Fisher, and K. R. Crooks. 2001. Factors influencing road-related amphibian mortality in Southern California p. 43. *In* Proceedings of the 2001 International Conference on Ecology and Transportation, [Eds.] Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.
Availability: Abstract Only

Evans, Jennifer; Laura Wewwerka, Edwin M. Everham III, and James Wohlpart. 2011. A large-scale snake mortality event. Herpetological Review 42 (2): 177-180.
Availability: Complete Document in Herp. Review
Florida

F

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, and J. F. Wegner. 1995. Effect of road traffic on amphibian density. Biological Conservation 73: 177-182.
Complete Paper

Frost, Darrel R., Taran Grant, Julián Faivovich, Raoul H. Bain, Alexander Haas, Célio F. B. Haddad, Rafael O. De Sá, Alan Channing, Mark Wilkinson, Stephen C. Donnellan, Christopher J. Raxworthy, Jonathan A. Campbell, Boris L. Blotto, Paul Moler, Robert C. Drewes, Ronald A. Nussbaum, John D. Lynch, David M. Green, and Ward C. Wheeler. 2006. The amphibian tree of life. Bulletin of the American Museum of Natural History Number 297. New York.
Complete Bulletin

Fowle, Suzanne C. 1996. Effects of roadkill mortality on the western painted turtle (Chrysemys picta belli) in the Mission Valley Western Montana. University of Montana report for Hwy 93 impacts. Cooperatuve effort MTDOT, Consolidated Tribes, and U of Mont Cooperarive Wildlife Research Unit. 20p.
Availability: Complete Document

Fusari, Margaret. July 1982. Feasibility of a highway crossing system for desert tortoises. Division of Transportation Planning, California Department of Transportation, Sacramento, CA. 41 p.
Availability: Complete Document Caltrans Library Call # M57-157

This was a pioneering study in road crossing by desert tortoises sponsored by Caltrans. The abstract as found in TRID follows:

> The habits of the desert tortoise were observed to determine their acceptance of culverts as a means of crossing highways. The observations were made in areas of high tortoise populations under three different conditions: (1) a set of three pens connected by different size culverts, (2) a mock highway culvert system with low drift fence to direct movements to the culverts, and (3) existing highway culverts for evidence of use without drift fences to direct movements. It has been determined that a portion of a tortoise population will accept culverts for crossing highways when directed by drift fences. There appears to be a learning period whereby a tortoise confronted with a fence culvert system several times soon makes more direct movements to a culvert rather than moving along a drift fence. A test of the results of this study under actual highway conditions is recommended. (FHWA) http://trid.trb.org/view/199178

G

Gibbons, J. Whitfield; David E. Scott, Travis J. Ryan, Kurt A. Buhlmann, Tracey D. Tuberville, Brian S. Metts, Judith L. Greene, Tony Mills, Yale Leiden, Sean Poppy, and Christopher T. Winne. 2000. The global decline of reptiles, déjà vu amphibians. BioScience 50(8):653-666.

Availability: Complete Document

This paper provides a general discussion of the global decline in reptiles as understood at the time of writing. It provides part of the general background for the preliminary investigation and subsequent work. These authors note the following significant threats to reptile populations globally:

- Habitat loss;
- Habitat degradation;
- Introduced invasive species;
- Environmental pollution;
- Disease;
- Unsustainable use; and
- Climate change

Gibbs, J. P. and W. G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. Conservation Biology 16:1647–1652.

Availability: Complete Document

Gibbs, James P. and W. Gregory Shriver. 2005. Can road mortality limit populations of pool-breeding amphibians? Wetlands Ecology and Management 13: 281-289.

Complete Paper

NYSDOT put money into this study

These authors performed a modeling study to estimate the potential for direct road mortality to result in extirpation of populations of *Ambystoma maculatum* Shaw in central and western Massachusetts. They concluded that a >10% mortality rate due to adults crossing roads could result in population extirpation and that between 22% and 73% of the populations in the study area would be exposed to this level of risk. The basic approach for modeling the probability of a salamander crossing a road for being killed should be adaptable for California.

Gibbs, James P. and David A. Steen. 2005. Trends in sex ratios of turtles in the United States: implications of road mortality. Conservation Biology 19 (2): 552-556.

Complete Paper

These authors synthesized 165 published estimates for sex ratios for 36 species published from 1928-2003. Their results suggest that over the time period of the literature the ratio of males to females became greater particularly in states with higher road density. The increase in males compared to females occurred in turtles with temperature sex determination despite the increase in temperature which would tend to lead to an increased number of females. The change in sex ratio was most apparent in aquatic species (in which females travel much more on land than males), than it was in semiaquatic and terrestrial species (where overland travel is more even between the sexes). The authors hypothesize that the change in sex ratio is due to is due to increased mortality of breeding female turtles due in part to highway mortality of nesting females.

Glista, David J., Travis L. Devault, and J. Andrew DeWoody. 2008. Vertebrate road mortality predominantly impacts amphibians. Herpetological Conservation and Biology 3 (1): 77-87.
Complete Paper

Glista, David J., Travis L. Devault, and J. Andrew DeWoody. 2009. A review of mitigation measures for reducing wildlife mortality on roadways. Landscape and Urban Planning 91: 1-7.
Complete Paper
Note: This paper lists Glista as being with the Indiana Department of Transportation
This is a recent literature review for wildlife in general including herptiles.

H

Hels, T. and Buchwald E. 2001. The effect of road kills on amphibian populations. *IN*: Proceedings of the 2001 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 25-42.
Complete Paper

Hoffman, Nelson. 2003. Frog fence along Vermont Route 2 in Sandbar Wildlife Management Area: collaboration between Vermont Agency of Transportation and Vermont Agency of Natural Resources p. 431-432. *In* ICOET 2003 Proceedings.
Availability: Extended Abstract Only in ICOET 2003 Herpetiles.
Temporary silt fencing was use to reduce mortality to northern leopard frogs as a short term solution in the Sandbar Wildlife Management Area in Vermont during the summer months. Culverts are proposed as a permanent solution.

J

Jackson, Scott D., and Michael Marchand. 1998. Use of a prototype tunnel by painted turtles, *Chrysemys picta*. Unpublished note. Department of Natural Resources Conservation, University of Massachussetts, Amherst.

Complete Note

The authors set up a 2 ft X 2 ft X 20 ft long wooden tunnel (not buried) and ca. 40 m of filter fabric drift fences on either side of the tunnel to guide the turtles to the tunnel. The location was in western MA. The tunnel was between a wetland and nesting habitat. Observations were made from 4 June to 25 June 1997. There were 35 encounters between the turtles and the drift fence (unknown number of individuals). On 5 occasions the turtles were disturbed by people and returned to the wetland without reaching the tunnel. Of the other encounters 20 reached the tunnel and all successfully traversed the tunnel mean time 113 sec, median 120 sec, range 60-197 sec. Painted turtles are not native to California but have some naturalized populations here. This brief work may inform strategies for western pond turtles also in the family Emydidae.

Jackson, Scott. 2003. Proposed design and considerations for use of amphibian and reptile tunnels in New England. Department of Natural Resources Conservation, University of Massachusetts, Amherst MA.

Complete Paper

Jackson developed a proposed design for herp tunnels based in his experience in MA. He notes that tunnels are experimental soJackson recommends tunnels only when: there is a known sensitive species population at risk; there is a distinct crossing location; traffic volumes are such that the populations are at risk from the increased mortality; the benefits of the tunnel outweigh the risks of blocked movement if tunnels are not functional; the tunnel is carefully designed and constructed; and maintenance will be done to keep the system functional. He mentions (but does not properly cite) occasions of tunnel failures for a mole salamander in CA [Allaback & Laabs?] and for *Emydoidea* in MA.

He recommends (and illustrates): a box culvert at least 2 ft X 2 ft with a minimal length to meet safety and design issues; PCC is suggested although “other materials are probably acceptable”; sandy soil should form the substrate for the tunnels; the top should be grated and open for light, air, and water; ca. 45° wing walls should be used; a vertical retaining wall at least 18” high, flush with the ground surface adjacent to the road, and around 100 ft – 200 ft should be used; crossings should not be greater than 200 ft apart. Stream simulation arched culverts and bridges with dry areas alongside the water are suggested for riparian species. Curbing is suggested for smaller roads and driveways.

Jochimsen, D. M. 2005. Factors Influencing the Road Mortality of Snakes on the Upper Snake River Plain, Idaho. *In* Proceedings of the 2005 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2006.

Availability: Complete Paper, also ICOET 2005 CD p. 351 This paper is posted at the eScholarship Repository, University of California.
http://repositories.cdlib.org/jmie/roadeco/Jochimsen2005a

Jochimsen, Denim M., Charles R. Peterson, Kimberly M. Andrews, and J. Whitfield Gibbons. 2004. A literature review of the effects of roads on amphibians and reptiles and the measures used to minimize those effects. Final Draft. Idaho Fish and Game Department, USDA Forest Service. 78 pp.

Complete Report

This report is one of a group of related works by Andrews, Gibbons, and Jochimsen that survey the literature related to the impacts of roads on herp populations. This report provides details on mitigation measures found by the authors in the literature to the time of writing. They discuss in moderate detail a variety of mitigation measures including: minimizing the impacts via planning, signage, physical transfer of animals, temporary road closures, culverts, tunnels, overpasses, fencing, and walls.

Jolivet, Renaud; Michel Antoniazza, Catherine Strehler-Perrin, and Antoine Gander. 2008. Impact of road mitigation measures on amphibian populations: a stage class population mathematical model. arXiv: 0806.4449v1.

Complete Paper

Note: arXiv [X is *chi*] is an archive for preprints of papers in a variety of fields including quantitative biology. The papers are not peer reviewed but a group of moderators for each area review the submissions. The system is operated by the Cornell Library. This site has long been important in the world of theoretical physics.

The authors analyzed the effectiveness of amphibian tunnels for *Bufo bufo* and *Rana temporaria* in Switzerland. A control set of populations was studied at Ostende, without a road, while the roaded area studied was in the Cheseaux area (ADT ca. 5500). The breeding and wintering sites in the two areas were comparable. The populations in the Cheseaux area were censused in 1983 and 1992-2004. The tunnel system was established in 1992. The control area was censused from 1994-2004. The authors observed a transient increase in adult migrating populations in the roaded area a few years after the construction of the mitigation. The population model study suggested that the tunnels facilitated the migrating population increase which was transient because of a shortage of habitat in the general area.

K

Karraker, Nancy E. and James P. Gibbs. 2011. Contrasting road effect signals in reproduction of long- versus short-lived amphibians. Hydrobiologia 664: 213-218.

Complete Paper

New York

These authors tested the hypothesis that road mortality exerts a greater effect on long lived species than shorter lived due to changes in population structure. The authors surmised that the older larger individuals would be selectively killed leading to the bulk of the egg masses being laid by younger smaller females. Thus the egg masses laid by K selected species near roadways would be smaller than egg masses laid by those species remote from roadways. Conversely, it was hypothesized that egg masses laid by R selected species should not vary in size in relation to distance from roadways. The two species that were selected were spotted salamanders (*Ambystoma maculatum*) representing K selected species and wood frogs (*Rana sylvatica* aka. *Lithobates sylvaticus*) representing R selected species. Spotted salamander egg masses were smaller in ponds near highways than in ponds remote from highways. Conversely, egg mass sizes did not differ for wood frogs. The authors note that an alternative explanation is poorer habitat quality for the salamanders near the road. A more tightly designed and executed study is recommended.

Kaye DR, Walsh KM, Rulison EL and Ross CC. 2006. Spotted turtle use of a culvert under relocated Route 44 in Carver, Massachusetts. IN: Proceedings of the 2005 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 426-432.

Complete Paper

MassHighway relocated Route 44 in Carver, MA beginning in 2002. To help preserve a spotted turtle (*Clemmys guttata*) population adjacent to the new alignment MassHighway changed from a proposed 24 in pipe culvert to a 6 ft X 6 ft box culvert. Post construction monitoring of turtle movements was conducted in 2004. Nine turtles were fitted with radio transmitters and thread bobbins. Turtles used the culvert as a crossing structure. Future study is recommended to understand continued use of the culvert as well as traffic and habitat alteration impacts on the turtle population.

Kobylarz, Beth. 2003 . The effect of road type and traffic intensity on amphibian road mortality. Journal of Service Learning in Conservation Biology. 1: 10-15.

Complete Paper

Kobylarsz studied the relationship between road type and traffic volume on amphibian road related mortality in the Land Between the Lakes National Recreation Area, KY. The two lane paved highway (US 68/80) had the highest amphibian mortality and could be “a driving force for negatively affecting amphibian populations”.

L

Langen Tom A., Angela Machniak, Erin K. Crowe, Charles Mangan, Daniel F. Marker, Neal Liddle, and Brian Roden. 2007. Methodologies for Surveying Herpetofauna Mortality on Rural Highways. Journal of Wildlife Management 71 (4) 1361-1368.

Complete Document

The authors evaluated walking surveys, driving surveys, and point counts over 976.4 km^2 in four towns (Potsdam, Canton, Lisbon, and Madrid) in St. Lawrence County, New York for utility in determining amphibian and reptile road mortality hotspots. They found that in the study area herptile road related mortality was both spatially and temporally clustered with the majority of deaths occurring in discrete areas over short periods of time typically in areas where there are wetlands on both sides of a highway. The mortality patterns remained the same from year to year. This clustering phenomenon allows a major reduction in road related mortality by mitigating in limited highway segment where mortality is the highest.

The authors determined that the point count survey methods that they used were not suitable for determining herptile mortality hotspots. They found that walking surveys provide the best estimates of the composition and magnitude of road-kill because driven surveys underestimate the magnitude of the mortality particularly for soft bodied amphibians. However walking surveys are both time and labor consuming. So the authors suggest a combination of walking and driving surveys. Driving surveys are used to cover large areas. Detection bias in the driven surveys can be estimated by walking a sample of the roads driven over and comparing results. Walking surveys are also recommended for verifying and delineating mortality hotspots. The surveys should be done over the entire period of herptile activity in an area.

The safety of the survey crews should always be of paramount importance.

Langen, Tom A., Kimberly M. Ogden, Lindsay L. Schwarting. 2009. Predicting hot spots of herpetofauna road mortality along highway networks. Journal of Wildlife Management 73: (1): 104-114.

Complete Document

For the purposes of application in California the most important aspect of this paper is the stepwise methodology for herptile mitigation measures. First, determine the spatial pattern of mortality based on valid survey data using valid survey methodologies. Second, determine landscape, road, or traffic pattern features that are correlated with the locations of high mortality in multiple locations. Third, create a protocol that can be applied by practitioners to identify mortality hotspots and hence potential locations for mitigation measures.

Lannoo, Michael. 2005. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley California. 1094 p.

Book Print Library

A comprehensive introduction to amphibian biology and amphibian declines. It contains 52 papers on a variety of amphibian related topics and detailed species accounts. There is a comprehensive bibliography.

Latch, Emily K., William I. Boarman, Andrew Walde, Robert Fleisher. 2011. Fine-scale analysis reveals cryptic landscape genetic structure in desert tortoises. PLoS ONE 6(11): e27794. doi:10.1371/journal.pone.0027794

Complete Paper

Latch et al. did a landscape and genetic study of desert tortoises in the Mohave Desert using 16 microsatellite loci. Their analysis indicated that the presence of roads influenced gene flow in the population studied.

Lesbarrerères, David and Lenore Fahrig. 2012. Measures to reduce population fragmentation by roads: what has worked and how do we know. Trends in Ecology and Evolution 27(7): 374-380. Accessed in Press by HGH on 2 May 2012 from Science Direct through American River College Library.

Complete Paper

This paper discusses the lack of rigorous literature on animal crossings for roads. The authors recommend using a properly constituted Before-After-Control-Impact (B-A-C-I) design for research and publishing the results in the peer reviewed literature.

The authors suggest using extended stream crossings that are about five times the width of the stream at high water with a height over the exposed banks high enough to allow for the passage of the largest animal in the area. They argue that this type of passage will allow connectivity of most animals. Additionally, they assert that “Overall, extended stream crossings are probably the most cost-effective way of improving connectivity across roads.”

The location of passages is also important as a element of their effectiveness. Relying on road kill data could prove deceptive because populations could already be depressed by direct or indirect mortality related to the presence of a road.

Lesbarrerères, David; Thierry Lodé and Juha Merilä. 2004. What type of amphibian tunnel could reduce road kills. Oryx 38 (2): 220- 223.

Complete Paper

This research team of European ecologists assessed the preferences of three French anurans common toads (*Bufo bufo*) (n = 41), water frogs (*Rana esculanta*) (n = 42), and agile frogs (*Rana dalmatina*) (n = 32) for utilizing or avoiding experimental tunnels constructed near the University of Angers, France during the period February – May 2001. Males and females were pooled during this study. The research team placed experimental animals on a grassy surface in front of two concrete pipes (0.5 m diameter by 2 m length). The pipes were directly adjacent to and parallel to one another. One pipe had a plain concrete bottom while the bottom of the other pipe was covered with sand and humus. Drift fencing guided the anurans to the mouths of the pipes. All testing occurred at night. The test animals were placed singly 1.2 m in front of the pipes and each individual animal was tested twice with a four day interval between tests. To "create a soothing environment for the animals" the researchers played recorded male breeding calls behind the test pipes. Each test lasted for ten minutes. The animals could choose to 1) remain on the grass, 2) enter the tunnel with the soil bottom, and 3) enter the tunnel with the concrete bottom. The distance that the animals penetrated into the pipes was assessed for those animals that entered them. Water frogs and common toads tended to enter the tunnels while agile frogs tended to remain on the grass. Common toads showed no preference for concrete or soil tunnel bottoms, however the two ranids showed a preference for soil bottoms when they entered the tunnels. There was no statistically significant difference in traversing success between concrete and soil tunnels. The authors speculate that alkalinity of the concrete may deter the frogs tested but not the toad. They also mention that anurans use olfactory cues during breeding migrations and smell may play a role in tunnel utilization. French engineers use water from nearby sources when tunnels are installed to encourage tunnel use. The authors recommend that amphibian underpasses have a soil substrate rather than a concrete bottom. Other factors that may be important in anuran crossing success include light intensity in the undercrossing, moisture in the tunnel, and proper use of fencing to guide animals to tunnels.

Lovich, Jeffrey E., Joshua R. Ennen, Sheila Madrak, and Bret Grover. 2011. Turtles, culverts, and alternative energy development: an unreported but potentially significant mortality threat to the desert tortoise (*Gopherus agassizii*). 2011. Chelonian Conservation and Biology 10(1): 124-129.

Complete Paper

This paper reports on the mortality of a listed desert tortoise in southern California by entombment of a hibernating tortoise by silt entering and filling a corrugated steel culvert about 60 cm in diameter during rainstorms. The authors suggest that larger diameter culverts with a diameter of 1m or greater should be used in desert tortoise habitat. Alternatively, tortoise excluders may be installed on smaller culverts, but care must be taken to prevent tortoises from going up onto road surfaces.

M

Mazerolle, Marc J. 2004. Amphibian road mortality in response to nightly variations in traffic intensity. Herpetologica 60(1): 45-53.

Complete Paper

The author did a multi-year study (1995-2002) using a night driving technique on 37 occasions to examine the impact of a low volume road (13.6 ± 5.9 vehicles/hour) in a national park in New Brunswick. 4643 amphibian crossings were recorded. The number of amphibians dead on the road did not vary during the eight years of the study. The greatest number of individuals died at "moderate" traffic densities of 10-18 vehicles per hour. Overall a "high mean mortality" (54% of ranids and 43% of caudates) was observed. Amphibian population sizes in the study area seemed not to be affected by the road mortality.

Mazarolle, Marc J., Matthieu Huot, and Mirelle Gravel. 2005. Behavior of amphibians in response to car traffic. Herpetologica 61(4): 380-388.

Complete Paper

The authors tested the behavioral response of a variety of eastern Canadian amphibians to the stimuli produced by traffic. The most common response was staying immobile, but there was variation among species. This work cannot be directly extended to California species, but it can inform how to set up similar studies here.

McCallum, Malcolm L. 2011. Road mortality of turtles and bullfrogs during a major flood. Herpetology Notes 4: 183-186.

Availability: Complete Paper

This paper documents greatly increased road mortality of turtles and frogs as they sought refuge on elevated roadways during a major flood.

McElhenny, Teresa and Andy Brookens. 2003. The preservation of bog turtle metapopulation dynamics by a transportation improvement project in southeastern Pennsylvania p. 467-471. *In* Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Availability: Complete Paper . This paper is posted at the eScholarship Repository, University of California. http://repositories.cdlib.org/jmie/roadeco/McElhenny2003a

This presentation documents the history of proposed mitigation measures for bog turtles (*Glyptemys muhlenbergii* then classified in the genus *Clemmys*) for a highway project in southeastern PA. The mitigation included replacing culverts with bridges.

Merrow, Jed. 2007. Effectiveness of Amphibian Mitigation Measures Along a New Highway p 370-376. *In* Proceedings of the 2007 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Debra Nelson, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2007.

Availability: Complete Paper This paper is posted at the eScholarship Repository, University of California. http://repositories.cdlib.org/jmie/roadeco/Merrow2007a

This presentation contains a design for an amphibian crossing tunnel for the Windham-Salem bypass project in New Hampshire. After three years there was no indication that the tunnel was being used.

N

Nelson, Debra A., Mary Ellen Papin, and Timothy Baker. 2006. Quick fixes: working together to address herptile road mortality in New York State, p. 90-93. In C. L. Irwin, P. Garrett, K. P. McDermott [eds]. Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Complete Paper Permalink:
http://escholarship.org/uc/item/3sm9p1qm

The authors describe work done to define and mitigate herptile road mortality in New York State during the early 2000's.

O

Olson, Deanna H. (coordinating editor) 2009. Herpetological conservation in northwestern North America. Northwestern Naturalist 90: 61-96.

Complete Paper

This paper provides an overview of conservation efforts including northern California.

P

Painter, Mikele and Michael F. Ingraldi. 2007. Use of simulated underpass crossing structures by flat-tailed horned lizards (*Phrynosoma mccallii*). FHWA-AZ-07-594. Arizona Department of Transportation. Phoenix, AZ. 38 p.

Complete Paper

The flat tailed horned lizard also occurs in California. This study was performed by personnel from the Arizona Game and Fish Department for the Arizona Department of Transportation. At a test facility near Yuma, AZ the research team tested six culverts of three dimensions and two interior lighting options. The culvert diameters tested were 24 in and 36 in steel culverts and 4 ft high by 8 ft wide concrete box culverts. All culverts were 40 ft long. One of each type of culvert was lit by a skylight while one of each type was lit only by natural light at the ends of the culverts. A total of 54 lizards were tested. Twelve complete crossings were observed. The 36 inch culverts with only natural lighting were crossed five times, 24 inch culverts with skylights were not used, each of the others was used once or twice. The authors recommend using fences to guide the lizards to the culverts.

Patrick, David A. and James P. Gibbs. 2009. Snake occurrences in grassland associated with road versus forest edges. Journal of Herpetology 43(4): 716-720.

Complete Paper

The authors conducted cover board surveys in grass covered old fields for common gartersnakes (*Thamnophis sirtalis*) and northern brown snakes (*Storeria dekayi dekayi*) in the Cicero Swamp Wildlife management Area in New York State. The study area contained a two lane paved rural road. They discovered no road effect zone in relation to abundance for these snakes. Proximity to the forest grassland boundary seemed to be of more importance to these snakes than proximity to the road. The presence of shade from the trees in the forest may have created poorer thermal conditions for these snakes. NYSDOT provided funding and 0.7m X 0.7m metal road signs as cover boards.

Patrick, David A., Christopher M. Schalk, James P. Gibbs, and Hara W. Woltz. 2010. Effective culvert placement and design to facilitate passage of amphibians across roads. Journal of Herpetology 44 (4): 618-626.

Complete Paper

The New York Department of Transportation provided support for this study.

This study was conducted at Labrador Hollow, Apulia, Onondaga County, New York. Its purposes were to determine factors that predicted where herptiles will be concentrated within a hotspot, and evaluate how the length, substrate and diameter of a pipe crossing influenced the movement of target species through the crossing. These target species were spotted salamanders (*Ambystoma maculatum*) and American toads (*Anaxyrus americanus*).

The author's hypothesized that the target amphibians would prefer to cross through wider shorter culverts and avoid moving over concrete. Additional hypotheses were that patterns of occurrence would be correlated to the locations of upland habitat suitable for over wintering and for breeding with a greater number of road crossings in closer proximity to the overwintering and breeding habitats. The authors did not expect that the presence of streams or seeps would determine the number of target amphibians crossing the road because movement of these species "invariably occurs" during rainfall and when the soil is saturated, or often when there is still snow on the ground.

The study site included a shallow lake bordered by forested wetlands. New York State Route 91, a two lane highway is on the east side of the lake and it separates upland terrestrial habitats from the aquatic habitats in the lake. There is a drainage channel on the upslope side of the road and culverts allow drainage across the road.

Experimental arrays of culverts with various attributes were established across the path of migrating salamanders.

The researchers observed that neither the toads nor the salamanders were primarily crossing the road by using the existing culverts perhaps due to the high volume and high velocity of water in the culverts due to snowmelt. The authors described the flow in the culverts during the migration period a “rushing torrent”.

The authors found that it was problematical to determine the occurrence within the hotspot of the spotted salamander based on local habitat attributes. The lack of detailed knowledge about the local movements of the target species seemed to have hampered the researcher’s ability to make detailed findings relating to habitat at small scale.

The culvert arrays experiment indicated that the spotted salamanders in the experimental area did not strongly select against any of the culvert attributes during migration. Any of the culverts would have permitted passage. This result differs from other studies looking at crossing attributes. The authors suggest that this difference in results may be due to inherent interspecific differences. Or the differences may be due to experimental animals modifying their behavior when relocated to “experimental arenas”.

The author’s note that the relatively short lengths of the culverts used (9 m) is shorter than many culverts used for highways. These culverts may be shorter than the threshold for non-use by the salamanders.

The authors note that studies in the eastern U. S. show that amphibians and reptiles have a higher probability of being found on roads near wetlands “especially where suitable terrestrial habitat is found on the aquatic-terrestrial interface”. (Does this relationship hold true in California?) Probabilities for herptiles to be on a road are generally higher when: roads and migration routes intersect and when nesting habitat is located on highway right-of-way.

In this paper the following steps are suggested for developing amphibian road crossings:

1. Determine the target herptile species.
2. Determine the location of herpetofauna and road hotspots.
3. Determine the attributes of the crossing structures that will make them acceptable for traversing by the target herpetofauna.

Amphibians particularly ranids are prone to desiccation in dry areas. Desiccation is enhanced by using concrete and gravel in long dry tunnels as the animals travel long distances over a dry surface. However amphibians are known to widely use culverts as long as 44 m.

Patrick, David A., James P. Gibbs, Donald J. Leopold, Peter K. Ducey, Hara W. Woltz, Daniel Crane, Frederic Beaudry, D. Viorel Popescu, and Chris Schalk. 2011. Effects of New York State Roadways on Amphibians and reptiles: a research and adaptive mitigation program (2011 Revision). New York Metropolitan Transportation Council, New York. 206 p.

Complete report available at:
http://www.utrc2.org/research/assets/101/Final-Amphibian_Reptile1.pdf

The primary objectives of this study were:

- Document the impacts of transportation infrastructure on herpetile populations.
- Determine the landscape, local habitat, and architectural attributes of effective herpetile crossing structures.
- Employ habitat analyses to identify "connectivity zones" where crossing structures would be most appropriately deployed along New York State roadways.

These objectives were met through seven research tasks which are reported as separate chapters in the research report:

- Road-kills, reptiles and amphibians: a synopsis and research agenda.
- Population structure and movements of freshwater turtles across a road-density gradient.
- Snake occurrences in grassland associated with road versus forest edges.
- The effects of proximity to roads on herpetofaunal abundance.
- Road crossing structures for amphibians and reptiles: informing design through behavioral analysis.
- Road-crossing behavior of amphibians: a case study from Labrador Hollow, New York State.
- Multi-scale habitat-resistance models for predicting road mortality "hotspots" for reptiles and amphibians.

The authors concluded that:

> This study can provide science-based guidance for mitigating the effects of road-mortality on herpetofauna, both in New York State and elsewhere in the northeastern United States. It is clear from our studies that roads have the capacity to influence both local and regional population dynamics of amphibians and reptiles. The degree to which road mortality affects populations seems highly dependent on the life-history characteristics of species and the degree to which natural habitat has been altered (both by roads and in other ways), however. Road mortality is of particular concern to populations of "K-selected" species such as turtles (i.e., species with high adult survival under natural conditions, late sexual maturity, and relatively low fecundity compared to other species of herpetofauna).
>
> The results of our experiments into the attributes of culverts that facilitate passage indicate strong evidence that differences in culvert design have the potential to influence choice, but our study of choice under natural conditions indicated that these differences might be muted when animals are motivated to move. When examining factors determining why animals cross in specific locations within known hotspots, we found clear differences between our two focal species, American toads and spotted salamanders, with these differences apparently related to variation in life-history strategies. The results of this study indicate that it is possible to predict where animals are likely to cross roads, but that these predictions should include consideration of the biology of individual species. Based on the habitat-associations of focal species, we were able to develop predictive hotspot maps for large areas of New York State. Our validation data indicated that the models we developed were good predictors of where animals were likely to occur on roads. We were also able to develop several metrics for prioritizing these hotspots for the purposes of mitigation. Together predictive models and the

results of our combined studies can be used to improve institutional capacity to mitigate the effects of roads on herpetofauna in New York State.

Care must be taken when attempting to adapt the findings of this New York study to California due to the differences in species, climate, and habitat between the two states. The following conclusions seem pertinent for use in California.

Amphibians and reptiles are susceptible to negative effects related to roads.

K-selected species that reach sexual maturity after an extended period, live for a long time period, and have relatively low annual reproductive rates are more susceptible to population effects from roads than R-selected species. Impacts to populations may not be reflected by mortality counts of individuals. For example pond breeding frogs may have greater mortality rates than turtles, but the higher fecundity of the rapidly breeding frogs may be able to absorb the casualties due to the high rate of reproduction.

More vagile species or segments of species (e. g. gravid female turtles) are more likely to encounter roads and be affected by them than are more sedentary species or segments of species.

Habitat alterations particularly those that stress herpetile populations can increase the affects of roads.

Animals that spend more time on the travelled way due to greater road crossing frequency, slow movement, freeze behavior when threatened, angle of crossing, or size of the roadway are more susceptible to being struck by vehicles than animals which spend less time on the travelled way.

The authors performed literature searches for each of the individual tasks. These citations range in date from 1951 to 2009.

In addition to the main research report this project produced a number presentations and peer reviewed journal articles including the following:

Predicting Desert Tortoise (*Gopherus agassizzii*) Habitat and Identifying Movement Patterns within the Proposed Highway 95 Realignment RIP Project 14989

Description in RIP database:

> State Route 95 has been proposed for expansion through one of the important desert tortoise Key Habitat Areas (KHA) within the State, and could irreversibly fragment the area if not properly placed and designed. Preliminary work within the KHA suggests a correlation between tortoise activity and Aridisol soil types, and shows promise as a tool to assist in proper placement of the new highway. Without this tool biologists lack the ability to predict and quantify important tortoise areas, and therefore fully assess the threat from the proposed Highway 95 project. Once proper placement of the alignment is determined, specific crossing structures to facilitate safe tortoise passage is needed. Two general variables are critical to the success of wildlife crossings: location and design. To determine the number and location of crossing structures, tortoise movement patterns must be understood prior to highway design. Finally, the proper type of crossing structures must be incorporated at each previously identified location so as to ensure an effective wildlife mitigation package for this highway project. This project will help Arizona Department of Transportation (ADOT) with compliance issues relevant to this sensitive species. Results for this project will allow for roadway designers to place the new highway 95 realignment in an area that has the least impact on desert tortoises, thereby reducing any possible delays caused by litigation. In addition, results from this study will allow for the most efficient placement of roadway

underpasses for desert tortoises, potentially saving dollars from arbitrarily placing structures where they are not needed.

Pough, F. Harvey, R. M. Andrews, J. E. Cadle, M. L. Crump, A. H. Savitzsky, and K. D. Wells. 2004. Herpetology. 3rd ed. Prentice Hall, Upper Saddle River, NJ. 726 p.

Book in Print Library

This textbook of herpetology discusses how the physiology of amphibians and reptiles influences their ecology and biogeography.

Puky, Miklós. 2003. Amphibian mitigation measures in Central Europe p. 413-429. *In* ICOET 2003 Proceedings.

Complete Paper in ICOET 2003 Herptiles and e scholarship

http://escholarship.org/uc/item/5bb7k6t9

This paper is a literature survey of information relating to amphibian mitigation including design and successful use by amphibians.

Puky, Miklós and Zsolt Vogel. 2003. Amphibian mitigation measures on Hungarian roads: design, efficiency, problems and possible improvement, need for a co-ordinated Europan environmental education strategy. Proceedings of the Infra Eco Network Europe 2003 – Habitat Fragmentation Due to Transportation Infrastructure.

Availability: Complete Paper

This presentation provides an overview of mitigation measures for amphibians in Hungary.

R

Roedenbeck, I. A., L. Fahrig, C. Scott Findlay, J. E. Houlahan, J. A. G. Jaeger, N. Klar, S. Kramer-Schadt, and E. A. Van der Grift. 2007. The Rauischholzhausen agenda for road ecology. *Ecology and Society* 12(1): 11. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art11/

Complete Paper

An important primer on the study design and interpretation of studies related to road impacts. The paper emphasizes the inferential strength and practicality of different study designs such as the Before-After-Control-Impact design and related designs. Also discussed is the selection of appropriate endpoints.

Rutherford, Jenny L. 2012. Glyptemys insculpta (Wood Turtle). Aggressive behavior. Natural History Notes. Herpetological Review 43(2): 326-327.

Availability: Complete Note Print Library

S

Samanns, Ed and Sebastian Zacharias. 2003. Mitigating potential impacts of herpetile habitat loss and fragmentation from new roadway construction in southern NewYork State p. 450-466. *In* ICOET 2003 Proceedings.

Availability: Complete Paper in ICOET 2003 Herpetiles.

http://escholarship.org/uc/item/27v2x0wz

This paper discusses proposed measures prior to construction.

Smith, Lora L. and C. Kenneth Dodd, Jr. 2003. Wildlife mortality on U.S. Highway 441 across Paynes Prairie, Alachua County, Florida. Florida Scientist 66(2): 128-140.

Availability : Complete Paper

Note: This paper is the before mitigation part of the study related to Dodd et al. 2004.

Stebbins, Robert C. 2003. A field guide to western reptiles and amphibians. 3rd ed. Peterson field guide series. Houghton Mifflin Co., New York, NY. 533 p.

Print Library

Storfer, Andrew, Jonathan M. Eastman, and Stephan F. Spear. 2009. Modern Molecular Methods for Amphibian Conservation. BioScience 59 (7): 559-571.

Complete Document

T

Torres, Aurora; Carlos Palacín, Javier Seoane, and Juan Alonso. 2011. Assessing the effects of a highway on a threatened species using Before-During-After and Before-During-After-Control-Impact designs. Biological Conservation 144: 2223-2232.

Complete Paper

This study provides an example of the application of Before-During-After and Before-During-After-Control-Impact designs.

U

Underwood, A. J. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. Journal of Experimental Marine Biology and Ecology 161: 145-178.

Complete Paper

The author discusses the sound design of sampling to be able to statistically determine if an impact is caused by a modification.

Underwood, A. J. 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications 4 (1): 3-15.

Complete Paper

The author discusses the sound design of sampling to be able to statistically determine if an impact is caused by a modification.

V

van der Ree, Rodney, Jochen A. G. Jaeger, Edgar A. van der Grift, and Anthony P. Clevenger. 2011. Effects of roads and traffic on wildlife populations and landscape function: road ecology is moving to larger scales. Ecology and Society 16 (1): 48 [online] URL:http://www.ecologyandsociety.org/vol16/iss1/art48/

W

Ward, Ryan Lee. 2005. The effects of roads and culverts on stream and stream-side salamander communities in eastern West Virginia. MSc. Thesis West Virginia University.

Availability Complete Thesis

Note: Published as Ward et al. 2008

and

Ward, Ryan L., James T. Anderson, and Petty J. Todd. 2008. Effects of road crossings on stream and streamside salamanders. Journal of Wildlife management 72 (3): 760-771.

Availability Complete Paper

Note: See Ward 2005 for the complete Thesis

This study done in the West Virginia Mountains concluded that the presence of roads reduced the densities of all local salamander species except for northern two-lined salamanders which are abundant in disturbed habitat. The authors suggest that impassible culverts are a problem in the area they studied and they recommend the use of culverts that "exceed channel width, are at grade with the streambed, and contain rubble substrate".

Wilson, Joseph S., and Seth Topham. 2009. The negative effects of barrier fencing on the desert tortoise (*Gopherus agassizii*) and non-target species: is there room for improvement? Contemporary Herpetology 2009 (3): 1-4.

Complete Paper

The authors note that fencing is in widespread use to prevent amphibians and reptiles from the road surface. While for the most part such fencing reduces mortality from tortoise-vehicle collisions there are negative aspects to using these fences. Animals that do manage to penetrate the fence may become trapped between the fence and the pavement where they may be killed by exposure. An additional problem is that when fences come together in an acute angle tortoises may become disoriented and remain in the angle for several hours. In one case the scutes of a tortoise's carapace became entangled in the hardware cloth type wire of the fences. The authors suggest that that escape methods be developed and installed in fences and that angles be rounded off when fences come together.

Woltz, Hara W., James P. Gibbs. 2008. Road crossing structures for amphibians and reptiles: informing design through behavioral analysis. Biological Conservation 141: 2745 – 2750.

Complete Paper

The researchers performed a series of behavioral choice experiments in New York State using snapping turtles (*Chelydra serpentina*), green frogs (*Rana clamitans*), northern leopard frogs (*Lithobates pipiens*), and painted turtles (*Chrysemys picta*). Only the northern leopard frogs may (or may not) be native to northeastern California. Tunnel aperture diameter, substrate type, length, and light permeability were tested. The authors concluded that "tunnels >0.5 m in diameter lined with soil or gravel and accompanied by 0.6-0.9 m high guide fencing would best facilitate road crossing for these and other likely frog and turtle species." These results cannot be directly applied to conditions in California without similar studies using local species. The main application is to utilize the methodology for studying California species.

A Conceptual Framework for Assessing Barrier Effects to Wildlife Populations Using Species Group Responses to Traffic Volume

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USDA Forest Service
Pacific Northwest Research Station*

Introduction

While studies indicate that traffic volume can be a useful tool for predicting impacts to wildlife populations, investigators have been hampered in their ability to use traffic volume predictively because responses among wildlife taxa vary widely. This paper proposes a conceptual framework that summarizes four general responses to increasing traffic volume. Understanding the response category of target species in a project development area enables project planners to better determine the likelihood of current or future impacts as well as appropriate mitigation measures. The objectives of this study were to investigate the role of wildlife behavioral responses to highway traffic volume as a predictive tool to determine barrier effects, to organize these responses in a conceptual framework, and to provide an early warning system that recognizes the rate of traffic volume growth as a trigger for mitigation.

Why Use Traffic Volume?

Traffic volume is a particularly useful metric because it is the basic unit of information used by transportation planners. Traffic volume data has been collected continuously since 1945 through the Highway Performance Maintenance System, which provides a generally uniform, consistent, statistically valid, and credible national level database built from State-provided data.

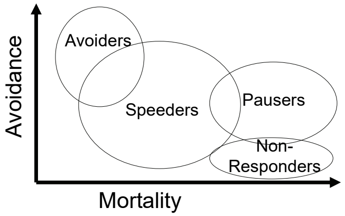
Highways as Barriers

Two highway-related impacts to wildlife are vehicle-caused mortality and movement barriers. Highways can cause barrier effects without mortality because some species will avoid the highway as traffic volume increases (Jaeger et al. 2005). For most terrestrial species, at a threshold volume, highways will become a complete barrier to movement because their probability of successfully crossing is zero due to the risk of mortality, even if a lack of behavioral constraints allows them to continue to attempt crossing. Barriers to animal movement are the focus of this paper.

Traffic volume is a good predictor of adverse effects to wildlife movement (Hels and Buchwald 2001, Trombulak and Frissell 2000). Combined with a framework of behavioral responses to traffic volume by wildlife, quantitative metrics can be better interpreted.

Four General Responses

The four response categories are: **Non-Responders, Pausers, Speeders,** and **Avoiders**. Barrier effects are primarily caused by mortality in the first two types and primarily caused by avoidance behaviors in the second two types. This concept does not apply to species that avoid the surface of the road due to its physical characteristics such as a lack of cover or hostile surface. While not all individuals in a population will react the same way, a high proportion of them will do so based on their sensory capabilities and behavioral responses to danger.

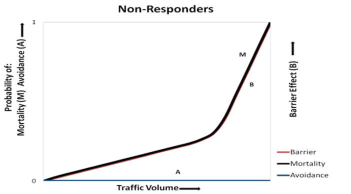


Responses to traffic volume do not fall cleanly along taxonomic lines.

Non-Responders

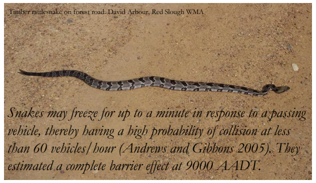
Non-Responders are characterized by a failure to detect or avoid lethal traffic, and continue regardless of traffic volume. This group is exemplified by invertebrates or lower vertebrates such as frogs or some snakes. As traffic volume increases, the probability of successfully crossing approaches zero, thus creating a complete barrier. The shape of the graph essentially follows the traffic flow model (Hels and Buchwald 2001; Van Langevelde and Jaarsma 2005). Non-Responders are at risk of having populations reduced through kill out as well as fragmentation effects.

Non-Responders are as diverse as this Oregon Silverspot Butterfly, endangered partly due to disproportionate vehicle-caused mortality of egg-depositing females, or frogs intent on breeding season movements.

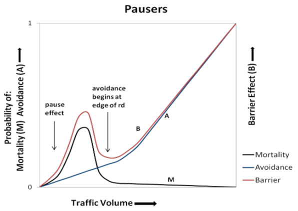


Pausers

Pausers can detect danger as traffic volume increases, but because the response is to stop in the face of danger, their risk of mortality increases with exposure such that the probability of successful crossing is nearly zero as traffic volume increases. Pausers include a variety of taxa in all vertebrate classes that exhibit responses such as crypsis, thanatosis, coiling in snakes, and simply stopping. Pausers are abundantly represented as roadkill, and include such common examples as skunks, porcupines, armadillos, and turtles. Complete barrier effects as traffic volume increases are both the result of high mortality as animals stop in the traffic lane, and can also be the result of avoidance at the edge of the road.

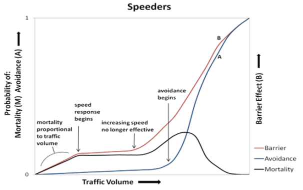


Snakes may freeze for up to a minute in response to a passing vehicle, thereby having a high probability of collision at less than 60 vehicles/hour (Andrews and Gibbons 2005). They estimated a complete barrier effect at 9000 AADT.



Speeders

Speeders flee from perceived danger with increased speed. Speeders can reduce the barrier effects of traffic volume increases by increasing their speed to exploit traffic gaps, but as traffic volume further increases and gap distance decreases, the probability of successfully running gaps decreases. Speeders include deer, pronghorn, and rapidly-moving snakes. Barrier effects manifest at higher traffic volume levels than the previous two groups because this group can respond with behavior that reduces mortality risk, but barrier effects do occur both as a result of mortality and ultimately avoidance of the road. Most ungulates would be characterized as speeders, and barrier effects as these more intelligent animals choose to avoid certain death manifest as increased avoidance.

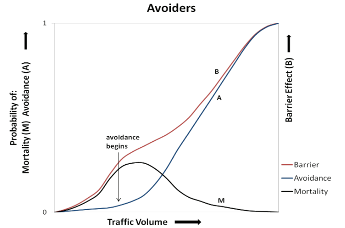


Radio-collared elk studies have shown that the most dangerous day for elk/vehicle collisions on the Tonto NF's highway SR260 is Monday when AADT is 35% lower than on weekends, as elk begin to move again after the weekend avoidance (Dodd et al 2006). Elk have a very high probability of successfully crossing highways because they move rapidly.

Avoiders

Avoiders avoid crossing attempts at fairly low traffic volume. They may modify their temporal behavior to avoid higher traffic volume periods of the day, thus effectively crossing only at lower traffic volume. This group has the lowest mortality rates because they recognize vehicles as dangerous. This group is exemplified by wary and intelligent species such as grizzly bears (*Ursus arctos*) and black bears (*Ursus americanus*). Barrier effects as traffic volume increases occur mostly through avoidance instead of mortality.

Intelligent bears run from danger, but learn to avoid traffic by modifying their activities. When that no longer works, they avoid crossing (Waller et al. 2006).



Implications

Understanding the response of species groups helps to accurately identify highway barrier impacts to populations, and to apply appropriate mitigation measures. This conceptual framework suggests that:

1. Some species are far more vulnerable at low traffic volume than others.
2. Vulnerability varies over time from mortality effects to barrier effects.
3. It may be important to mitigate mortality effects on moderate traffic volume highways.
4. Carcass data must be interpreted carefully to avoid interpreting lack of mortality as evidence of lack of a connectivity issue.
5. As traffic volume increases, mortality may be so severe in Non-Responders and Pausers that local populations are wiped out, so decreased evidence of roadkill may signal an advanced problem rather than a lack of problem.
6. As traffic volume increases, safety issues from animal/vehicle collisions may decrease with Speeders and Avoiders, thus reducing the need for DOTs to mitigate collisions, but not solving the animal movement issues.
7. Varying responses by species suggests that highways function as behavioral filters as well as mortality filters, and the rates of both vary with traffic volume.

If empirically confirmed for several species, traffic volume can be useful as an early warning trigger for DOTs and resource managers.
Future research might beneficially illuminate the approximate mortality and avoidance thresholds by species.

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