Title
Combining Aquatic and Terrestrial Passage Design into a Continuous Discipline

Permalink
https://escholarship.org/uc/item/6w6573r8

Authors
Jacobson, Sandra L.
Gubernick, Bob
Furniss, Michael J.

Publication Date
2007-05-20

COMBINING AQUATIC AND TERRESTRIAL PASSAGE DESIGN INTO A CONTINUOUS DISCIPLINE

Sandra L. Jacobson (541-678-5240, sjacobson@fs.fed.us), Wildlife Biologist, USDA Forest Service, Pacific Southwest Research Station, Arcata, CA (Contact Address: 19546 Meadowbrook, Bend, OR 97702) USA
Robert Gubernick (907-772-5840, rgubernick@fs.fed.us), Engineering Geologist, USDA Forest Service, Tongass National Forest, Box 309, Petersburg, AK 99833 USA
Michael J. Furniss (707-825-2925, mfurniss@fs.fed.us), Hydrologist, USDA Forest Service, Pacific Northwest and Pacific Southwest Research Stations, Redwood Sciences Lab, 1700 Bayview Street, Arcata, CA 95521 USA

Abstract: Transportation planners occasionally notice a curious lack of consistency and communication between hydrologists, fisheries biologists and wildlife biologists regarding passages designed for their respective specialties. Several substantial differences in treatments between aquatic and terrestrial passages at highways masks the majority of similarities. At one end of the continuum, aquatics passages can be characterized by a total containment within a watercourse, with no need for modification of the shape or size of water conveyance structure as long as the structure maintains hydrological functionality. At the opposite end of the continuum terrestrial passages can be intentionally designed to avoid water conveyance entirely. Between these two extremes lie similarities in the need for functional streamcourses that allow passage for all age classes of fish and wildlife, as well as high water events. Our paper discusses the common mistakes made when considering only one passage category and suggests remedies designed to integrate the needs of terrestrial and aquatic organism passages. Our paper also discusses the professional basis for the occasional forgetfulness in dealing with other disciplines using lessons learned on this topic by the USDA Forest Service as an interdisciplinary land management agency.

Introduction

Designing passages across roads for aquatic and terrestrial animals, separately or together, is relatively new. Examples of successful and unsuccessful passage designs are available and instructive. As time passes, and adequate performance becomes more common for both general categories of taxa, it appears the science and practice of aquatic passage design compared to terrestrial passage design might be diverging rather than converging. Fisheries biologists often do not discuss terrestrial passage needs with wildlife biologists and wildlife biologists often fail to recognize important cues where terrestrial passage needs are important.

Limited funding, limited time, and unpredictable weather patterns resulting from climate change are all excellent reasons why transportation ecologists can no longer afford to consider aquatic or terrestrial passages separately. Opportunities to increase habitat connectivity taken when they arise may cost considerably less and provide timely restoration or maintenance of passage needs for all taxa as well as ecological processes. This paper attempts to identify barriers to simultaneous consideration of passage needs for all vertebrate species, and to suggest solutions for a new paradigm broadly considering all species. This paper primarily considers the lessons we have learned on integrating vertebrate passage needs.

In this paper, aquatic organism passage (AOP) will broadly refer to passage opportunities and planning for fish and other organisms that are primarily confined to the watercourse or wetted streambanks; terrestrial organism passage (TOP) will be applied for vertebrates that are not confined to water or wetted streambanks, although they may use riparian systems as a necessary habitat component.

Although we have considered these questions primarily from the perspective of a federal land management agency, our experiences indicate that the USDA Forest Service is not alone in experiencing the issues identified here.

Objectives

The objectives of this paper are:

- To identify characteristics of passages effective for both aquatic and terrestrial species
- To identify practices effective for either aquatics or terrestrials but not both
- To identify practices that cause problems for one group while solving problems for the other group
- To identify planning solutions to obtaining passages effective for all taxa

Aquatic and Terrestrial Passages are Often Considered Separately

In the USDA Forest Service, fisheries and wildlife biology responsibilities are usually borne by different people. Because there is always more work to do than people to do it, biologists often do not interact on projects, especially where past experience has led them to believe there are no substantive issues. Some passage situations clearly do not require both disciplines to provide planning input.

Our experience and those of many others is that fisheries biologists and wildlife biologists view passage needs differently. Commonly, both biological disciplines assume that small roads, especially native surface roads or those with low traffic volume, do not require TOP consideration because they do not cause obvious mortality problems for large mammals and less obvious disruption of movements. This is usually true, so it masks the cases where those problems do occur. Mitigation may be needed for mortality and habitat connectivity issues even on small, low volume roads especially in cases where slow reptiles and amphibians occur in populations of management concern, where road surfaces are anticipated to be upgraded or widened, or where traffic volume is anticipated to grow within the next decade.

Both wildlife and fisheries biologists have limited knowledge and training of passage needs for their discipline. Fisheries biologists tend to have greater knowledge and training on passage issues than wildlife biologists. Fewer still have training in passage needs for both disciplines, and we are aware of no integrated training currently available that is as detailed as training available separately. This may result in unsophisticated or uninformed input, or overlooking important passage needs, on projects in the planning phase.

There has been and continues to be a legal imperative to find passage solutions particularly for endangered anadromous fish. The urgency and magnitude of these needs have led some managers to avoid considering other species of any type because it may slow progress towards these mandated goals. Funding sources based on annual appropriations or special budget line items do not lend themselves to careful deliberation, and funds not spent on passage needs for the species targeted are not likely to be available in the future. Thus urgency is combined with the practical approach that passage for some species is better than passage for no species.

As the science and practice of AOP has matured, increasingly well-defined and specific guidelines have emerged. For examples, see Gubernick et al (2003), Furniss et al (1999), and Conner et al (2003). Wildlife biologists have been invited to participate in these efforts but have not had as mature practice to inform TOP.

Terrestrial organism passage is fundamentally different than aquatic organism passage. The most obvious difference is that terrestrial animals are not confined to water, so the intersection of crossing locations with roads is not necessarily an identifiable point. Other differences such as the relatively high intelligence of some terrestrial animals means that behavior can be highly unpredictable even in well-studied species. Nothing analogous to the level of detail of such predictive modeling tools as Fish Xing (http://www.stream.fs.fed.us/fishxing/index.html) is available for terrestrial species, and even limited guides with recommendations on sizes and other attributes of crossing structures are properly laced with qualifiers. Although some organizing principles have emerged on TOP practice in the last two decades, terrestrial biologists are still far from the level of detailed guidance and training that AOP practitioners have obtained.

Aquatic passages are more technically complex than upland terrestrial passages in considerations of the range of changes and fluctuations of the stream throughout the life of the structure. Terrestrial passages are more complex than aquatic passages in considerations of the range of sizes and intelligence levels of multiple target species, and the difficulty of determining the best location and configuration for the structure. For both, a major complexity is determining whether or not a structure is needed and for which species.

Identification of Passage Needs For AOP and TOP

A primary need in the search for an integrated AOP and TOP practice is identifying barriers, passage impediments and the degree of importance for animals to move across a road without suffering population-impacting mortality. This has been much more refined in AOP than TOP, with some agencies and states having procedures and policies to identify and prioritize AOP needs (Forest Service Regions 6 and 10, for example). Few efforts have been made to integrate large-scale AOP or TOP needs, and we are aware of only a few large project-level integration attempts. The Interstate 90 Snoqualmie Pass, Washington, improvement project has integrated AOP and TOP objectives and has performance measures identified to meet both needs. For example, alternatives recommend replacing existing bridges confining the channel at Gold Creek with bridges that would provide better channel functionality as well as greater opportunities for wildlife passage (figure 1). On smaller projects, such as individual Forest Service culvert replacement projects, we are aware of many individual specialists who attempt to integrate disciplines. In some of these cases, a greater understanding is needed to identify the trigger points for when both AOP and TOP are needed.

Figure 1. Aerial view of Gold Creek on Interstate 90 (Washington DOT image). At this site, project objectives include providing wildlife and fish passage for the full range of lake elevations.

Although we have much to learn about what triggers the need for passage in both taxa groups, some organizing principles can be identified.

Considerations for AOP

Certain stream/road intersection issues can be more associated with AOP than TOP. Many complex factors contribute to effective AOP design, however our discussion is limited to those that contrast or compare to TOP considerations.

Obviously, streamflows constrain fish presence and location. Other aquatic taxa are similarly dependent on watercourses. Aside from the simple presence of water, stream and channel characteristics also govern what species are present and what passage needs and constraints they have. Roadway elevation can affect the options available for underpasses, and therefore the effectiveness of the structure for the target species. The road condition at the streamcourse/road intersection influences AOP when it affects water quality such as sedimentation, and the shape and length of underpasses. For example, a wide road may affect AOP because of the length of the passage through the fill. Streams are rarely straight for long distances whereas structures may be. This may cause delays for fish attempting to pass through, which can be critical for some species. Multiple culverts on the same stream may also cause critical delays.

AOPs can be planned for the conditions of the watershed rather than the conditions of the road surface itself. AOPs can be sized to allow for the expected range of hydrologic conditions, including debris passage and the avoidance of pressurized flow conditions, rather than additional headroom for species that use the air above the surface. To the extent that water conveyance structures are planned to simulate the natural flow conditions, AOP is probably maintained.

Considerations for TOP

Terrestrial animals may travel far away from water even if they prefer riparian habitats. This makes their road crossing locations much more difficult to pinpoint for planning passage structures, and makes it important to consider characteristics of the entire floodplain even in riparian obligates. Sizes of terrestrial animals cover a wider range than aquatic species, ranging from tiny shrews to moose or elephants, thus requiring consideration for a physical structure that at the very least will encompass the basic size of the animal plus a behavioral comfort factor that varies by species. Conditions within the structure also constrain how terrestrial animals move through it. As with some fish, light or lack of light or air temperature can be important, while water temperature is not important because terrestrials may avoid walking in the water itself. While designing passages to avoid fatigue in migrating fish is important, terrestrial animals may not suffer appreciably more fatigue than walking over normal terrain unless they are trying to swim upstream in a culvert or negotiate boulder armaments at bridge abutments.

The greatest difference in aquatic and terrestrial considerations is the condition of the roadway and traffic in addition to the passage structure itself. For permeable-skinned animals such as salamanders, frogs and toads, the road surface can preclude passage due to the dry, hardened road surface or contaminants including deicing or dust abatement agents. As the number of lanes increase, the more time individuals spend on hostile surfaces during crossing attempts and the greater their opportunity for perishing.

Traffic volume and the capacity improvements (including additional lanes or median barriers) that transportation departments use to manage volume have a major effect on the probability of successful TOP (Hels and Buchwald 2001, Van Langevelde and Jaarsma 2005). The presence of a median barrier and guardrails may affect the ability of animals to cross a highway. Many other factors affect successful TOP, but in comparison to AOP the primary difference is that what happens on the road itself has as much of a bearing on the ability of terrestrial animals to pass as the size, gradient and location of passages for aquatic species.

Traffic volume can be very low for impacts to begin to manifest in vehicle-caused mortality or loss of permeability. Breeding European common toads (*Bufo bufo*) suffered 30% mortality while crossing a 6 m wide road with 10 vehicles per hour (Van Gelder 1973). Excessive adult mortality of the slowly reproducing wood turtle (*Clemmys insculpta*) was found at around 100 vehicles/lane/day (Gibbs and Shriver 2002). Intensively graded forest roads 12 m wide were a significant barrier for three species of terrestrial salamanders investigated in Maine (DeMaynadier and Hunter 2000). Narrow gravel roads were determined to be partial barriers to salamander movement and steep roadside verges may contribute to the effect (Marsh et al 2005). Indigo snakes (*Drymarchon corais*) that respond to passing traffic can be restricted from crossing with as few as 10 vehicles per hour (Andrews and Gibbons 2006). Even large mammals, especially wary ones, can be adversely affected by small amounts of traffic; grizzly bears (*Ursus arctos horribilis*) begin to avoid roads at traffic volumes of less than 10 vehicles per day (Mace et al. 1996). Movements were impaired for carnivores in winter in Canada when traffic ranged from 300-500 vehicles per day, and for ungulates between 500 and 5000 vehicles per day (Alexander et al 2005). While these studies and others do not necessarily support the need for TOP on all roads, they do suggest that roads with very low volume can be impermeable to some species due to mortality and barrier effects. Slow species are at greater risk because of greater exposure to mortality risk on the road (Hels and Buchwald 2001). Especially for reptiles and amphibians, speed of vehicles is unlikely to be a factor in mortality because of the low visibility of these animals. Thus, while increasing traffic volume and width of the road cause increasing impacts to slow and small animals, even relatively low volume and low speed roads can cause substantial adverse impacts. The context of these impacts including the legal status of the species involved as well as the management objectives will determine the degree and type of mitigation required.

While designs for AOP need to predict a watershed's changes and fluctuations over time, designs for TOP need to predict the increases in traffic volume over time (figure 2). For both groups, the temporal considerations would ideally span the expected lifespan of a prospective underpass design, but in reality structures may last far longer than a reasonable forecast for either traffic volume or watershed conditions.

Figure 2. Predicting traffic volume is important when considering terrestrial passage needs within the functional lifespan of a proposed water conveyance structure. Although gravel only few decades ago, this highway has a current ADT at this location of 22,760 and is projected to be 38,700 by 2028 (Oregon DOT). Photo S. Jacobson.

Passage Conditions That are Ineffective for Both AOP and TOP

Passages designed for effective passage for only one taxa group may or may not be suitable for both groups. However, conditions that are unsuitable for one taxa group suggest that conditions may be unsuitable for the other as well. In general, a passage that simulates natural conditions to the extent possible is more likely to meet the needs of all of the species in the area. Stream simulation in culvert design is one approach used in some western states; this approach assumes that while we may not understand all the factors involved in designing effective stream crossings, a stream/road intersection that appears and functions similar to the way the original stream functioned prior to the presence of a road will likely meet the needs of the original inhabitants of the stream.

If a stream crossing is not designed to function like the original channel, several construction methods adversely affect the passage of both aquatic and terrestrial animals. High gradient culverts, especially if they are long and more than 25% of the natural gradient of the stream, are difficult for fish to swim up without exhaustion, and they are difficult or impossible for most terrestrial animals to climb. Perched outlets higher than fish can jump are well-known fish barriers, but they are also barriers to terrestrial species. Conversely, shallow inlets and outlets, or shallow water spread out all through a culvert can be a depth barrier to fish, yet even a shallow skim of water in a structure may be enough to hinder terrestrial animals that prefer dry areas to walk through a structure. The type of substrate on the structure floor may hinder aquatic or terrestrial species if it does not provide suitable soil, gravel size, and moisture conditions (moist to dry). Box culverts with an inch of water might create a shallow depth barrier for fish but a deep barrier for mice. Slick concrete aprons are also often depth and velocity barriers for fish, and may not allow a purchase for terrestrial species.

Passages that are Effective for one TAXA Group but Ineffective or Dangerous for the Other

Because TOP can occur far away from water and would not be designed to handle AOP, these types clearly do not afford AOP. A special case where dry underpasses for TOP are constructed high in the fill slope of a highway that also has a water conveyance structure are not dangerous for AOP but, by mitigating only for TOP, planners may lose an opportunity to replace a long or steep gradient culvert with one suitable for AOP. A bridge would handle both needs. Because not all streams and stream reaches have aquatic passage needs, this may not be an issue if carefully analyzed during planning. Several terrestrial species are known to prefer traveling on dry surfaces alongside watercourses. Shelves of concrete or other material placed along the side of a culvert that is wall to wall water provides dry passage for animals (Foresman 2004). This is an effective retrofit for terrestrial animals but does not remedy any aquatic passage issues present, such as shallow depth barriers in box culverts.

Fish passage structures can sometimes be dangerous to terrestrial species. Typically, these are structures that have been designed to slow high flows and provide resting areas for passing organisms, and so few terrestrial species may try to use them unless forced to seek a way across a road. Fish ladders or weirs with deep submerged sides may trap terrestrial species that attempt to use the underpasses (figure 3). The shelves mentioned above would be a possible retrofit for some of these structures provided they did not unduly hinder the hydrologic function of the structure.

Figure 3. Vertical walls used to provide resting pools for fish may trap terrestrial animals. A horizontal shelf along the edge of the culvert is a possible retrofit to allow terrestrial animals dry walking space. Photo from Fish Xing.

Effective AOPs that are not dangerous to terrestrial animals but may cause avoidance include structures with very low headroom inadequate for an animal to use either behaviorally or simply due to size, or box or metal culverts with deep outlets that reach both sides of the structure with no unsubmerged areas (figure 4).

Figure 4. The right culvert chamber has a perched inlet (shown left). Combined with the same culvert's inundated outlet (right), it is difficult for many terrestrial animals to use. Photos S. Jacobson.

Many bridge replacements are being constructed with boulder armament protection from the water line to the abutments (figure 5). These bridges are often sized large enough to be superb crossing structures for many species of wildlife but fail to be useful because the armament only allows passage for nimble species that can safely clamber over rocks. Small animals including turtles can get trapped in the spaces between rocks, and ungulates avoid riprap altogether.

Figure 5. Bridge replaced in 2007 with excellent shape and size to allow passage for all terrestrial species present in the area, but rendered impermeable for many terrestrials due to the large boulder armament. This type of abutment protection is very common in current bridge replacements. Photos S. Jacobson.

Attributes of Effective Integrated Passages

Several principles can be identified for creating effective passages. First and foremost, specialists need to jointly consider the passage needs of any and all organisms early in any project, especially in site assessment and the early determination of design criteria. Passages that retain the natural gradient, substrate and width of a streamcourse along with unwetted sides provide good insurance for any principles not yet clearly identified. These features add complexity and hydraulic condition variability that are found in the natural stream. Underpasses that consider adequate headroom for terrestrial species while designing for flood events also allow for debris passage and avoid pressurized flow conditions that cause damage to streamcourses. Climate change models suggest that extreme events will become more frequent, so a prudent practice may be oversizing culverts and bridges to accommodate larger flood events than past records allow us to predict. Several states including Arizona, Vermont and California are considering climate change as a planning factor. These features can be designed into culverts or bridges as needed, and bridge replacements offer an excellent opportunity to incorporate integrated aquatic and terrestrial passage principles into the designs.

Social and Agency Solutions to Integrating TOP and AOP

Identifying the need to integrate terrestrial and aquatic passages entails two conceptual frames. The large-scale, long term transportation planning process can provide consideration of habitat connectivity and mortality reduction needs for both broad taxa groups, while project-level planning can provide information on site specific needs. Ideally, connectivity needs would be identified prior to transportation project planning, both at the large scale and project scale, but in practice the transportation planning process often provides the catalyst for change. Thus far, identification and prioritization of AOP and TOP needs has been mostly done separately on a broad scale. Examples are the Forest Service's Region 6 aquatic passage priority setting process, and the growing number of state wildlife habitat connectivity plans. To some extent, the separation is due to inadequate funds for a comprehensive integrated process.

Research is needed on how best to identify the highest priority sites so that scarce resources are not expended on retrofitting or replacing structures that were built, but have neglected to consider all species' needs. Policy direction for land management agencies and departments of transportation would be useful in breaking down administrative barriers. Processes such as the interagency Eco-Logical planning approach (Brown 2006) hold promise for helping to accomplish integrated planning and design, while State Wildlife Action Plans could be integrated better with the few aquatic organism passage priority systems available. Agencies that take full advantage of the collaboration intent of SAFETEA-LU's Section 6001 and 6002 will be further ahead on interagency cooperation and efficient use of limited resources.

Evaluation of the passage and mortality reduction needs at each site is a primary need before we can effectively integrate AOP and TOP. This will require a better understanding of the temporal and spatial triggers for the need for habitat connectivity and mortality reduction for aquatic and terrestrial resources.

Training in channel types such as the Rosgen (1994) classification system would enable wildlife biologists to have a common language with physical scientists, engineers, hydrologists, and fisheries biologists on the engineering limitations and geomorphic requirements for each situation. Understanding channel types can help determine where crossing structures might be placed to best accommodate AOP and TOP together, or if it would be necessary to treat them separately. For example, road crossings over Rosgen channel types B, C, D, DA, and E have the potential to readily accommodate both AOP and TOP if the crossings are designed with those needs in mind, while other channel types may be possible but require more challenging engineering solutions.

Identifying project level sites where mitigation is needed for passage for both groups of taxa can be best accomplished with an interdisciplinary team early in the project planning process. Even when interdisciplinary teams are employed, it is necessary for each member of the team to have adequate knowledge of the factors that influence the need for each type of passage. Currently, both halves of this equation, involvement and knowledge, are inconsistently available. One objective of this paper is to identify some of the attributes of road/stream crossings that are ripe for consideration for both taxa groups.

Interdisciplinary teams that consider the long-term conditions of both the road and the stream will likely be more able to identify and prioritize passage opportunities. Knowledge of this topic is rapidly growing, so teams that investigate solutions through innovative methods can make significant contributions to integrating passage needs for both aquatic and terrestrial organisms that need to cross roads and highways.

Biographical Sketches: Sandra Jacobson is a wildlife biologist specializing in wildlife and highway interactions with the USDA Forest Service, Pacific Southwest Research Station.

Robert Gubernick is an engineering geologist and the lead fish passage/ hydraulic engineer for the Tongass N.F. Alaska Region of the USFS.

Michael J. Furniss is a hydrologist and boundary spanner with the USDA Forest Service, Pacific Northwest and Pacific Southwest Research Stations, located at Redwood Sciences Lab, Arcata, CA.

References

Alexander, S.M., N.M. Waters and P.C. Paquet. 2005. Traffic volume and highway permeability for a mammalian community in the Canadian Rocky Mountains. The Canadian Geographer 49:321-331.

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

Brown, J. 2006. Eco-Logical: an ecosystem approach to developing infrastructure projects. FHWA Report FHWA-HEP-06-011. Washington DC. 83 pages.

Connor, A. Clarkin, K., Furniss, M., Gubernick, R., Moynahan, K., Wilson-Musser, S. 2003. National Inventory and Assessment Procedure for Identifying Barriers to Aquatic Organsim Passage at Road-Stream Crossings. USDA Forest Service.

DeMaynadier, P.G. and M. L. Hunter Jr. 2000. Road effects on amphibian movements in a forested landscape. Natural Areas Journal 20: 55-65.

Foresman, K.R. 2004. Small mammal use of modified culverts on the Lolo South project of Western Montana - an update. 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: pp. 342-343.

Furniss, M., Moore, T., Love M., Dunklin, T., Gubernick, R., Firor, S., Lang, M., Roelofs, T. and B. Rush. 1999. FishXing: New Software under Development to Assist in the Analysis of Fish Passage Through Culverts. Engineering Field Notes Volume 31.

Gibbs, J.P. and W.G. Shriver 2002. Estimating the effects of road mortality on turtle populations. Conservation Biology 16 (6), 1647–1652.

Gubernick. R. and K. K. Bates. 2003. Designing culverts for aquatic organism passage: stream simulation culvert design. 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: pp. 42-52.

Hels, T. and E. Buchwald. 2001. The effect of road kills on amphibian populations. Biological Conservation 99: 331-340.

Mace, R.D, J.S. Waller, T.L. Manley, L.J. Lyon, and H. Zuuring. 1996. Relationships among grizzly bears, roads and habitat in the Swan Mountains, Montana. Journal of Applied Ecology 33: 1395-1404.

Marsh, D.M, G.S. Milam, N.P. Gorham, and N.G. Beckman. 2005. Forest roads as partial barriers to terrestrial salamander movement. Conservation Biology 19: 2004-2008.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22:169-199.

Van Gelder, J.J. 1973 A quantitative approach to the mortality resulting from traffic in a population of *Bufo bufo* L. Oecologia 13: 93-95.

Van Langevelde, F. and C.F. Jaarsma. 2005. Using traffic flow theory to model traffic mortality in mammals. Landscape Ecology 19: 895-907.