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Technical Guide for Field Practitioners: Understanding and Monitoring Aquatic Organism Passage at Road-Stream Crossings

Nicholas Heredia

Brett Roper

Nathaniel Gillespie

Craig Roghair

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Contents

Introduction

Stream connectivity has become increasingly important for river restoration and fish-habitat improvement projects (Fullerton et al. 2010) amidst increasing evidence that it plays a vital role in supporting aquatic organism populations (Roni et al. 2002; Gibson et al. 2005) and species diversity (Nislow et al. 2011). Recent emphasis on identifying and removing barriers in order to restore aquatic organism passage (AOP) is based on well-documented negative effects of road-stream crossings on fish (Rieman et al. 1997; Hudy et al. 2005) and the potential for cost-effective restoration of aquatic habitat. However, challenges remain in identifying barriers and prioritizing road-stream crossings for remediation. The U.S. Department of Agriculture Forest Service (USFS) has been working to stream-line the process of identifying and remediating road-stream crossings that are inadequate for AOP.

The USFS manages approximately 370,000 miles of roads and replaces between 150-300 road-stream crossings annually, indicating a need for prioritizing restoration projects. While not specific to USFS land, a study of road-stream crossings in the Great Lakes region indicated that only 36% of locations were fully passable by fish (Januchowski-Hartley et al. 2013). Past USFS road-stream crossing remediation efforts have produced varying degrees of success, as measured by newly available habitat per dollar spent. The need to ensure that AOP projects are implemented correctly coupled with the challenge to prioritize AOP among many potential aquatic barrier road-stream crossings creates the need for a comprehensive and concise protocol for road-stream crossing AOP assessments.

Because identifying potential barriers to AOP can be difficult and costly, we suggest the following steps for focusing barrier remediation efforts:

1) Identify locations of road-stream crossings,
2) Determine passability of barriers, and
3) Identify where remediation efforts will be most effective to achieve goals and objectives.

Each of these steps can range in scope, complexity, and required effort, making proper decisions a challenging step. For example, determining AOP at a specific barrier could range from direct observation (Kemp and O'hanley 2011), which requires little training, to telemetry (Aarestrup et al. 2003) or genetic studies (Wofford et al. 2005; Neville and Peterson 2014), which require considerable resources and expertise. Selecting an assessment technique should consider the type of results desired and whether they have implications for an individual species, a group of similar species, or multiple populations across a number of watersheds. It is critical to determine the desired goals and objective of an AOP project prior to implementing an in-depth assessment.

In most cases, multiple barriers will fragment an aquatic system or watershed. Among and within river connectivity is of primary concern when assessing options to remediate multiple barriers to aquatic organism movement. A number of studies outline the importance of assessing the potential gains to aquatic organisms in relation to the multiple barriers that may exist in the system. Cote et al. (2008) describe a good example of how to use spatial data to assess which barriers may best improve habitat for stream fishes. Bourne et al. (2011), like Cote et al. (2008), incorporates information on barrier passability, lengths of stream reaches adjacent to barriers, and total stream length to calculate indices of river connectivity. In this protocol, we describe how these types of indices can be used to compare before and after scenarios of passability for a given set of barriers within a watershed to determine which barrier remediation(s) would be most effective at expanding aquatic organism access to new habitat. These indices will be explained later in the section regarding indices of connectivity.

Purpose and Content of This Protocol

This protocol seeks to be a cost-efficient guide for assessing and prioritizing road-stream crossings that potentially act as barriers to aquatic organisms. While this guide identifies step-by-step instructions for assessing AOP at road-stream crossings it was intentionally built to allow users to substitute more region- or species-specific tools if available and well suited. It is intended for use by individuals with some level of familiarity with hydrology and fluvial geomorphology. Some level of training is recommended for citizen volunteers.

This guide is intended to:

1) Insure a project's objective and scale are set.
2) Address AOP at sites primarily using a quick and repeatable rapid assessment filter (Level-1 survey).
3) In areas where more precise measurements of fish passage are needed, we suggest FishXing should be the primary more in-depth assessment technique (Level-2).
4) Prioritize and select remediation sites based on the project's objectives and these physical survey of site characteristics.
5) Work with researchers to identify a limited number of sites where assessing fish movement with more intensive Level-2 survey techniques will improve our Level-1 surveys and/or parameterization of fish movement attributes within the FishXing software.
6) Discuss a suite of biological-based options for effectiveness monitoring of individual road-stream crossings.

Protocol: Decision Tree

The flow chart (Figure 1) depicts the biological decision making process for conducting an AOP assessment project. The decision tree is designed to provide managers and other interested parties with step-by-step instructions to evaluate the impact of potential barriers, prioritize the remediation of AOP barriers, and to evaluate the effectiveness of AOP designs that have been constructed in the past.

The decision tree is comprised of the following steps:

1) Determine the appropriate scale for the project based on project objective and biological constraints of the species or aquatic community being considered.
2) Conduct field assessments with a time-effective physical monitoring approach (Level-1), which is relatively simple, effective, and repeatable.
3) Use spatial assessment techniques to prioritize crossings that are potential barriers to AOP at the proper scale.
4) Use results from step 3 to prioritize crossings that should be targeted for a Level-2 assessment using additional measurements required by FishXing.
5) Conduct FishXing assessments at crossings in need of Level-2 surveys. While there may be a few sites nationally where more intensive Level-2 assessments should be conducted to improve parameterization of FishXing software and Level-1 surveys, rarely should measurements of actual fish passage be necessary to determine whether a road crossing should need to be modified to improve aquatic passage.
6) After completing Level-1 surveys as supplemented with FishXing assessments, revisit the spatial assessment of stream crossings in the project area that are and are not fish passage barriers to determine which crossings will provide the most ecological benefits from remediation.
7) Provide guidance on determining the most effective and efficient remediation strategy for restoring aquatic connectivity at the individual stream reach, metapopulation, or population scale.
8) For a small subset of road-stream crossings where substantial monetary investment is needed and federal ESA-listed species benefit remains unclear, choose from a suite of biological-based monitoring options for assessing stream passage.
9) Be aware of the planned replacement schedule of road-stream crossings by agency, state or municipal engineers based on age and condition of the structure, as well as whether potential partners have prioritized or secured funding for upgrading specific crossings. This information may inform your prioritization scheme.

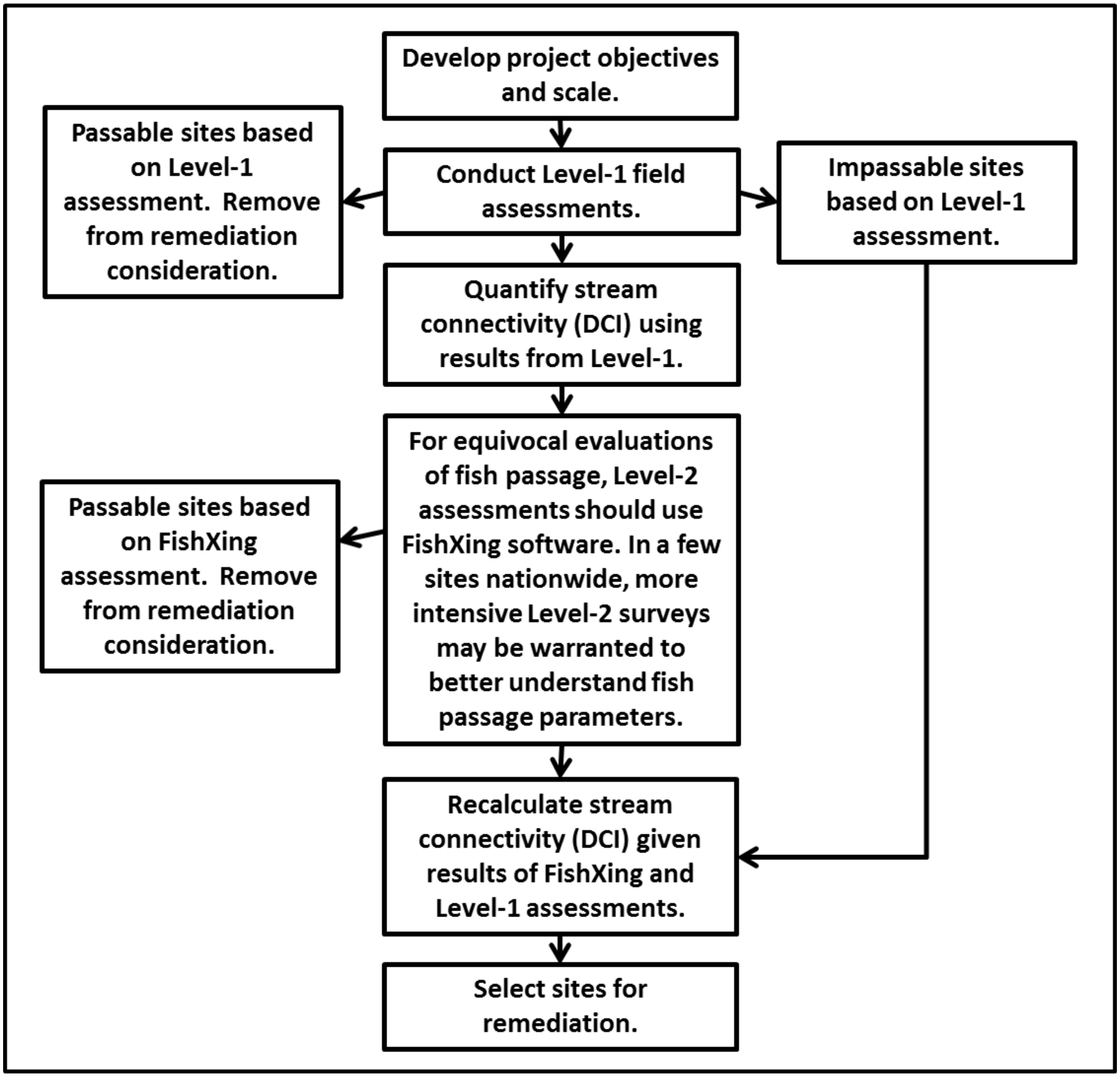

Figure 1. Aquatic Organism Passage assessment project decision tree.

Step 1: Project Objective and Scale

The first step in assessing AOP at road-stream crossings is to determine a project objective (Figure 1). Project objectives may range from improving AOP at a single road-stream crossing to increasing gene diversity within a population. In the latter case, it will be necessary to determine the catchment or geographic boundaries that confine the species or stock of concern while in the first case knowledge at the site scale is likely sufficient. As noted by Kemp and O'hanley (2010), an AOP project objective should focus on "mitigating the effects that barriers have on key ecological processes along the longitudinal (Vannote et al. 1980) and lateral (Junk et al. 1989) dimensions." Longitudinal dimensions refer to the linear characteristic of a stream while lateral dimensions refer to the dendritic nature of multiple streams in a catchment or watershed.

While linking objectives to life-history traits, key ecological processes, or important habitat are important, other restrictions will often dictate project objectives. Factors related to human capacity will also limit project scale which will limit the project objectives. The number of sites that can be assessed at a given stage, the number of sites that could potentially be remediated, and the number of available personnel hours will all be dictated by funding and should be taken into account prior to conducting any field assessments.

Important Considerations When Selecting a Catchment or Area for Assessment:

- Is the area important for specific life history traits (e.g. spawning, winter habitat, and juvenile survival)?
- Will access to the area be limited by barriers outside of the area being considered for assessment? If so, can those potential barriers be assessed?
- Is the area likely to maintain good habitat following barrier remediation efforts (i.e. are regulations in place that will maintain good habitat)?
- Does the species of concern migrate to or from this area as part of its life history?
- Does the area contain critical habitat for an endangered, threatened, or sensitive species?
- Is the area important for other aquatic biota?
- Has the area already been assessed for AOP by another agency? If so, are data from that agency available?
- How many road-stream crossings need to be assessed within the given area?
- How many remediation projects will funding and personnel-power allow for?
- Are invasive species a concern and will restoring aquatic connectivity threaten native aquatic populations?

Step 2: Locating Road-Stream Crossings

Prior to conducting field work (Level-1 assessment) road-stream crossings and potential barriers should be identified using road and stream maps, GIS, or other spatial tools. Selecting a tool should be done with consideration for project scale and the process of calculating stream connectivity (see Step 4). For instance, with smaller projects (1 – 10 potential barriers) a simple spread sheet may suffice. Larger projects may need a spatial tool like GIS to be employed.

If multiple road-stream crossings are to be identified and assessed then adding a spatial assessment component should be conducted and can be accomplished using a number of techniques. However, in some cases, when the location of a potential culvert remediation project is already known, it is still important to assess how effective an AOP improvement project will be. As an example, replacing a culvert with a low probability of fish passability may have limited value to the fish population if other nearby natural barriers restrict movement or if the newly available habitat is limited in length or poor in quality. In these cases, remediation efforts may be more effective elsewhere.

Cote et al. (2009) point to a number of connectivity factors that should be considered prior to initiating remediation efforts and we cover these in Step 4: Prioritization of Road-Stream Crossings. For instance, their study found barriers to movement near the mouths of main stem rivers had the biggest negative impact on stream connectivity for diadromous species (those requiring lake or ocean and stream habitat to complete life cycle), while barriers near the center of stream networks had the biggest impact on potadromous species (those that use stream habitats year-round and do not migrate to a lake or ocean). The same study also found the first few barriers to movement added to a system had a much bigger impact on stream connectivity than subsequent barrier additions in the same system. This suggests that removing one barrier from a system with many barriers may not result in a large increase in connectivity, and subsequent increases in species diversity or genetic diversity. Below are steps for locating road-stream crossings that are potential barriers to AOP.

Steps for Locating Potential Barriers to AOP:

1) Based on life-history strategy of the species or stock of concern, determine the boundaries or catchment that outlines the area to be assessed.
2) Use maps, GIS, or other spatial tool to identify locations of road-stream crossings or other boundaries that may exist within the catchment.
3) Determine the route between potential barriers that will minimize travel time and distance.
4) Record coordinates of potential barriers in a GPS unit or other navigation system.
5) Gather appropriate field equipment for conducting a Level-1 assessment (see next section).

Quick, Repeatable, and Consistent Field Assessment

We've synthesized a first-phase Physical Assessment technique designed to quickly, consistently, and repeatedly assess a large number of road-stream crossings that builds on published literature and compiles multiple techniques into one step. This Level-1 assessment draws from both stream simulation design standards and easily collectable physical measurements. The physical measurements in the Level-1 Physical Assessment can be used in more in-depth Level-2 physical assessments such as FishXing. While studies have shown that physical assessment protocols may not match results from biological assessments, physical assessments are often conservative. This indicates that some aquatic organisms will pass through some barriers that physical assessments suggest they cannot pass through. Given partial passability is also found following more intensive and costly evaluations of fish movement, we suggest there will rarely be a need to conduct Level-2 surveys that are more intensive than FishXing. Assuming road crossings that are deemed impassable by FishXing are at least partially impassable will increase the speed a basin can be assessed without sacrificing overall accuracy of that assessment. Using the same Level-1 technique for each potential barrier is important for consistency, and should ensure results identify the barriers with limited AOP. Past work has suggested that for a given study, culverts that rank poorly in regards to AOP will rank poorly no matter the physical assessment technique used (Bourne et al. 2011; Anderson et al. 2012). Additionally, developing a Level-1 physical assessment technique which incorporates past protocols allows managers to quickly identify culverts and road-stream crossings as potential barriers to AOP and targets for mitigation.

Physical measurements of culverts can be used in many different ways to assess whether aquatic organism passage is possible. Known physical performance capabilities (swimming speeds, jumping abilities, minimum water depth needed for movement) of specific species can be compared to the physical measurements collected for a coarse filter or in rule-based simulation software (e.g. FishXing). Our Level-1 assessment uses a quick and repeatable coarse filter, while FS-developed simulation software such as FishXing requires more precise data. Although our coarse filter is developed from data collected on fish species that are commonly found throughout streams in North America, more regional- or species specific filters may be available for your study area. We suggest using a regional- or species-specific filter as long as the selected filter is easily repeatable and requires little time per site.

Because physical assessment protocols for assessing AOP at road-stream crossings tend to be conservative we intend this step to act as a screen for crossings that can quickly be eliminated from further consideration for remediation efforts. The general design of the coarse filter (Box 1) indicates that road-stream crossings that maintain natural stream conditions throughout a barrier should be considered passable.

Box 1:

Characteristics of suitable passability

- Road-stream crossing maintains a width which is greater than or equal to that of the adjacent upstream and downstream reaches.
- Contains natural stream substrate and flow throughout.
- Does not have a perched outlet.

For example, if a road-stream crossing maintains a width which is wider than the upstream and downstream bankfull channel widths, contains natural stream substrate and flow throughout, and does not have a perched outlet, then it should be considered passable and no further analysis should be conducted for the purposes of assessing AOP. If these criteria are not met, then proceeding with collecting physical measurements as described in the coarse filter should be conducted. Once the locations of road-stream crossings are identified for assessment, the first step should be to visit each site and determine whether the road-stream crossing is physically passable, not passable, or needs further investigation. This can take many different forms, but if the crossing is a bridge or culvert with flow and substrate characteristics similar to that of the surrounding upstream and downstream reaches of stream (Figure 2), then the crossing should be deemed passable and no further assessment should be necessary. However, if the crossing consists of a cement or pipe culvert and does not maintain natural substrate throughout nor is it backwatered from the downstream end (Figure 3), then physical measurements (Box 2) should be collected to assess whether AOP is possible, or whether further steps need to be taken to determine the effectiveness of the crossing for AOP.

Box 2:

Minimum Physical measurements to be collected

- Culvert length
- Slope of culvert
- Outflow pool depth
- Outflow drop height (perch height)

At a minimum, the physical measurements that should be collected are culvert length, slope, outflow pool depth, and outflow drop height (if the outflow is not submerged in the downstream pool). These types of measurements (and others, depending on the protocol used) can be used to assess whether fish (or other aquatic organisms) have the ability to pass through the culvert (see Bourne et al. 2011).

Figure 2. Culvert built to mimic natural stream reaches. The stream flow and substrate within the culvert remains similar to that of the adjacent upstream and downstream reaches. In this case fish passage should be assumed.

Figure 3. A road-stream crossing that does not mimic natural stream reaches, but may still allow AOP for certain species. A Level-1 physical assessment should be conducted.

Preparation for the Level-1 physical assessments:

1) Access: Ensure access is possible to all desired sites. If necessary, obtain appropriate permission or permits for conducting field work.
2) Sampling equipment
    - GPS or map depicting locations of road-stream crossings.
    - Measuring tape.
    - Data sheets from Appendix (page 34).
    - Survey rod and level.
    - Protective equipment such as helmets and wading boots/waders.
    - Camera.

Steps for the Level-1 physical assessment are outlined below:

1) Determine if the stream resembles a natural (Figures 2, 3, and 4) stream channel (Box 1). Characteristics that indicate natural stream conditions include (taken from Clarkin et al. 2005):
    a) Streambed slope, substrate particle size, and substrate arrangement are similar to adjacent sections of stream, and substrate is visible on the streambed throughout the crossing.
    b) The crossing is as wide, or wider, than the bankfull channel width in the adjacent upstream section of stream.
    c) Is the entire crossing backwatered from the downstream pool? If yes, the crossing should be considered passable. four different road/steam crossings top

Figure 4. Pictures in the upper two panels depict road-stream crossings that could be considered to mimic natural stream conditions, while the two lower pictures show crossings that clearly do not meet those criteria. The top two culverts appear to maintain natural stream flow similar to adjacent reaches and contain natural substrate similar to upstream and downstream reaches, whereas the bottom left culvert does not maintain an opening wider than the channel width, and the bottom right culvert has an outlet perch height greater than 150% of that of the outflow pool depth

2) If a crossing is not to grade, does not have a natural substrate on the bottom of the channel, or does not span the base flow stream channel, conduct a Level-1 physical assessment and collect the necessary measurements (Figure 6). Select which filter to use based on species. See coarse filters in Figure 5 and the Appendix (pages 32 & 33).

3) Record data in database for future reference.

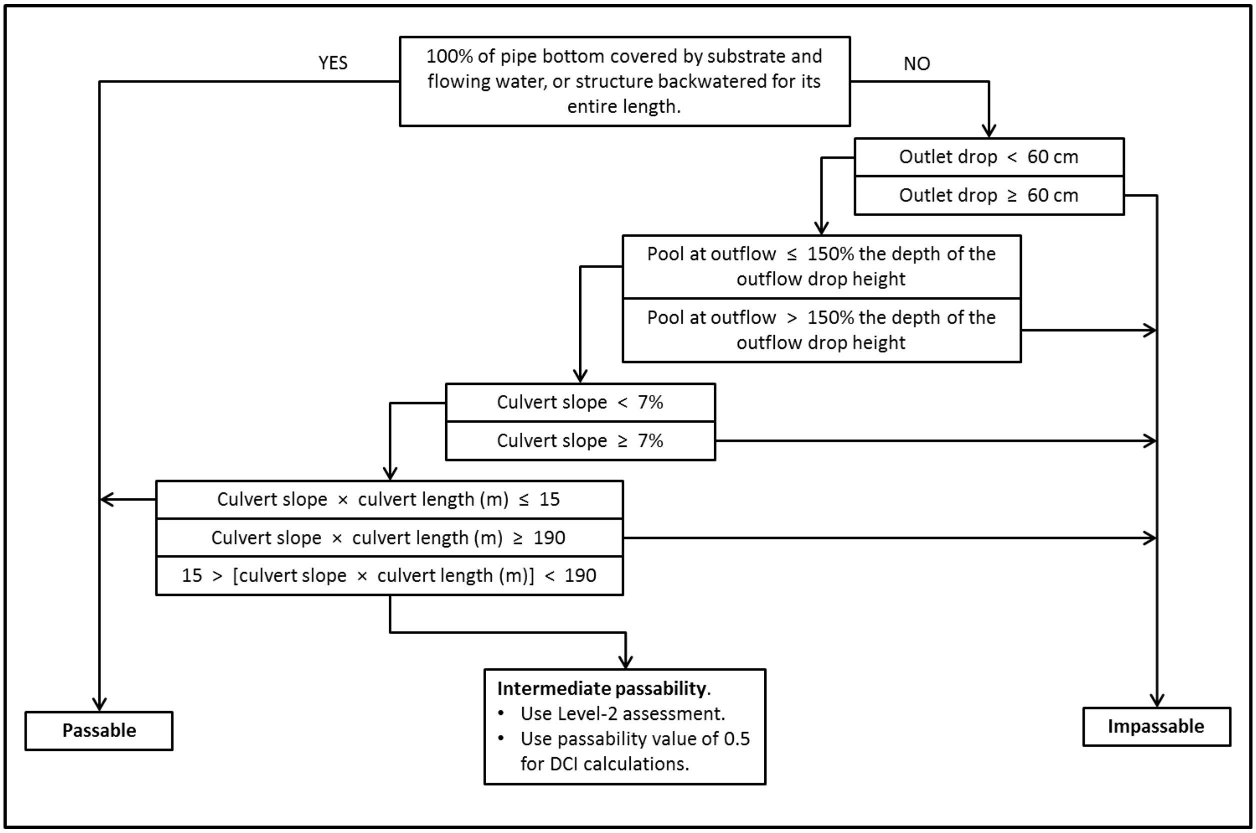

Figure 5. Coarse filter for Level-1 physical assessment for adult salmonids. Flow chart is modified from those developed in Coffman et al. (2005) and Bourne et al. (2011). See pages 29 & 30 in the Appendix for coarse filters modified for young-of-the-year salmonids and cyprinids, and for percids and cottids.

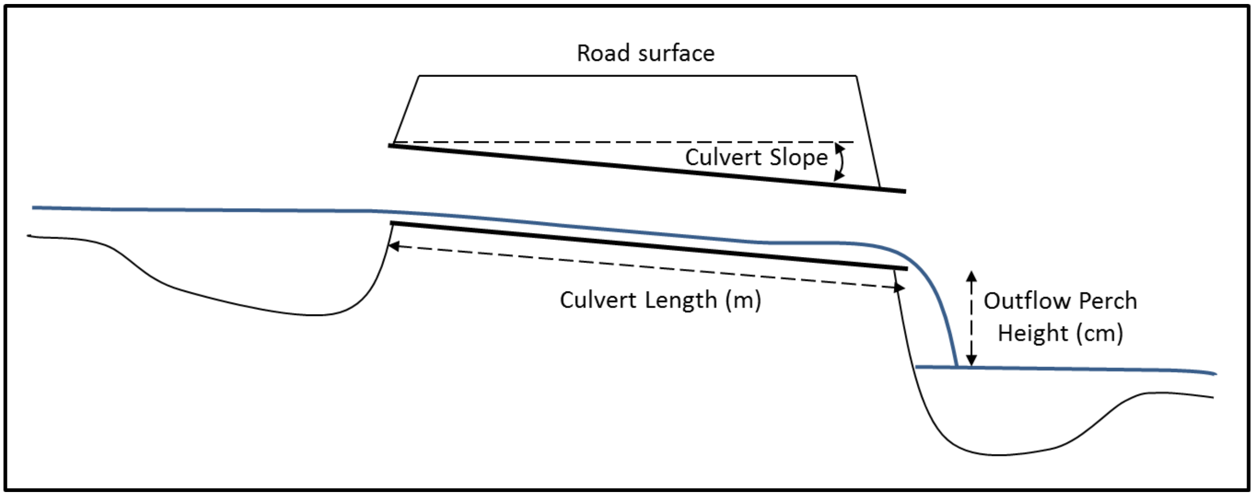

Figure 6. Profile view schematic of a road-stream crossing which depicts measurements needed for the Level-1 coarse filter.

As noted earlier, the Level-1 physical assessment is employed to act as a first phase technique to quickly identify road-stream crossings that can be confidently ruled out as potential barriers to AOP. Those road-stream crossings that are identified as limited passability, intermediate passability, or yield inconclusive results should be targeted for a more rigorous Level-2 physical assessment technique. In all but a few cases the best Level-2 approach will be FishXing because it is cost effective and likely conservative for the species of interest.

As previously mentioned, prior to conducting Level-1 assessments, we suggest reviewing the data needs for the Level-2 protocol FishXing. In some cases, it is reasonable that FishXing assessments may be warranted and/or conducted prior to conducting a Level-1 assessment. In particular, being prepared to conduct a FishXing assessments during the same site visit as for a Level-1 assessment may save substantial time and effort. If it is known that it is likely that the more specific measurements needed for FishXing will be used, we suggest bringing all equipment to a site required to conduct a Level-1 and FishXing assessment during the same visit.

Step 4: Prioritizing Road-Stream Crossings / Calculating DCI

Stream connectivity can be assessed a number of different ways, some of which incorporate factors related to habitat quality, miles of available stream length, or both. In this protocol, we focus on stream length and connectivity, and not on habitat quality, though, we describe how a habitat quality component could be added. Described below are two dendritic connectivity indices (DCIs) that could be employed to assess stream connectivity both before and after remediation efforts, as well as prior to implementing any Level-2 AOP assessment. Drawing comparisons between pre-remediation conditions and potential scenarios that could be observed, given improved passability at certain road-stream crossings, can be used to determine which barrier removals will result in the largest benefit for a desired species. While this type of prioritization process is important for assessing which barriers should be remediated, it also becomes useful when assessing which barriers should be considered for the more time-consuming and costly Level-2 AOP assessment techniques. This will help to focus efforts on barriers which will yield the biggest returns to aquatic organisms. Additionally, the DCI calculations explained here can be supplemented with species-specific habitat quality models and data. The McKay et al. 2016 article in *River Resources and Applications* provides a synthesis of various barrier removal prioritization schemes to consider: http://onlinelibrary.wiley.com/doi/10.1002/rra.3021/epdf.

At the catchment scale we suggest using measures of dendritic connectivity described in Cote et al. (2009) and shown below. They discuss measuring the connectivity of streams based on two styles of use by stream dwelling organisms. Below, we describe how to calculate stream connectivity for potadromous (year-round stream resident organisms) and diadromous aquatic organisms (requiring stream habitat as well as lake or ocean habitat). The DCI for diadromous organisms is calculated as;

where l_i is length of stream segment i, L is the total stream length of the system, and and are the upstream and downstream passabilities of barrier m, respectively. DCI_P is calculated as follows:

where C_{ij} represents passability between l_j and l_j If passability is different depending on direction of movement, then can be substituted for C_{ij}. Additionally, when considering segments on the opposing ends of multiple barriers, than C_{ij} will be the product of all the barriers between the two segments. See Appendix 1 for an example of how to perform these calculations.

From these calculations, we suggest creating before and after scenarios that can be used to compare road-stream crossing remediation efforts and how they may affect overall connectivity. These calculations should be performed prior to implementing Level-2 AOP assessments at specific sites and should be revisited again after implementing actual remediation.

The ability of aquatic invasive species to access upstream habitat can be a concern to fisheries managers (Fausch et al. 2008). Similar to calculating indices of stream connectivity, we suggest reviewing the unintended consequences of improving AOP throughout the process of an AOP assessment project. This, again, will aid in focusing costs and effort on the areas or potential barriers of most concern. McLaughlin et al. (2013) provide an overview of the potential unwanted biological effects of improving AOP through road-stream crossings (and other barriers) and these include unwanted introductions above the barrier location, altered predator-prey and competitive interactions, reduced selectivity at partial barrier locations, and many others.

Steps for implementing a DCI:

Record the distances upstream of road-stream crossings that contain good habitat with their respective passability values as determined from the Level-1 assessment.

If desirable, add a habitat quality component which is scaled from 0-1 (note: score for habitat should be between 0.5-1 if stream maintains year-round flow).

Calculate DCI for a given catchment, given the appropriate passability values.

Conduct scenarios for connectivity given potential for improved passability at poor crossings. Note: when calculating DCI for a system wherein more than one road-stream crossing may be remediated it is important to recalculate DCI after assuming one of the other impassable crossings has been remediated. This will affect how the placement of additional remediation efforts will alter DCI.

Designate sites that most reduce connectivity; these will be the sites most likely subject to Level-2 assessments.

Adding a Habitat Quality component:

While the DCI calculations do not include a term for accounting for habitat quality, we suggest one could be added but should be done in a cautionary manner. A habitat component (some measure of habitat quality from 0-1) could be multiplied by the passability value and stream length for each stream reach being considered. However, because this will have a multiplicative effect, the habitat quality component could greatly influence the DCI value for a given catchment. Therefore, we suggest taking precautionary measures that would ensure that the habitat quality does not override the access to even poor quality habitat. For instance a stream with water flowing throughout the year is better than no habitat at all so we suggest even the poorest quality stream should rate at least 0.5 for stream resident species. Likewise, if a stream is ephemeral but maintains healthy stream flow throughout the spawning and rearing season of an anadromous species of concern, then a habitat quality value should be at least 0.5, even though during some parts of the year the stream reach has no surface flow.

Step 5: Level-2 Assessment Techniques

After completing the Level-1 assessments and calculating the indices of stream connectivity for a given area of interest, a good understanding of how aquatic biota movement is affected by passage at road crossings should have been achieved. In some situations this understanding can be improved by a more in-depth Level-2 physical assessment technique such as FishXing. There will be few situations where direct evaluations of site conditions are needed to improve decisions relative to AOP. Additional Level-2 assessment approaches are identified here primarily for edification. In the few cases where direct measures of fish movement are desired, we encourage forest personnel to work with state or federal researchers to develop a study design that not only improves our understanding of fish movement at the site implemented, but also at the Regional or National scale.

Techniques for monitoring the effectiveness for AOP of road-stream crossings can vary depending on the desired response, whether it is at the individual level or population level, and scale (i.e., one culvert vs. many culverts). Additionally, available funds and personnel will greatly affect which options will be applied to a given project. Nonetheless, prior to implementing a Level-2 assessment, thorough review of the study approaches and their limitations should be undertaken. Kemp and O'hanley (2010) give a good review of some different approaches for monitoring AOP effectiveness of barriers to fish passage. However, this guide will go over the pros, cons, and results that can be made from the Level-2 assessments described herein.

Level-2 Assessment Techniques

Prior to conducting any of the following Level-2 assessments beyond FishXing, be sure to go through the following steps.

1. Determine the potential scale of culvert remediation within your assessment area over a given time-scale.
2. Determine if more precise direct measures of fish passage will improve project decisions.
3. Attain appropriate permits.
    a. Biological sampling permits.
    b. Construction permits.
4. Use DCI calculations to determine which culverts to focus on for Level-2 assessments.

FishXing

FishXing software was developed by the USDA Forest Service for evaluating fish passage at road-stream culverts. FishXing evaluates the passability of a potential culvert barrier based on known fish swimming speeds and jumping abilities, hydraulic characteristics of a culvert, and physical dimensions of that culvert. FishXing estimates whether fish movement is restricted given a range of hydraulic and physical conditions. While FishXing does not directly measure fish movement, and is therefore subject to error, it does require less time in the field than many of the other Level-2 assessments. However, studies comparing fish movements in relation to potential barriers to those studies that directly measured fish movement indicated that FishXing passability predictions are relatively conservative, specifically in regards to passable flows (Mahlum 2014). Below we describe general instructions for conducting an assessment of fish passage at road-stream crossings using FishXing software. The reader should consult the FishXing web page for more specific directions (http://www.stream.fs.fed.us/fishxing/).

1. Identify the location of potential barriers using GIS, road-stream maps, or other spatial assessment tool.
2. Review FishXing software.
    a. Review the FishXing Introductory Tutorial prior to conducting any field assessments. If the fish species of concern does not have swimming performance criteria within the FishXing database, then either review the published literature for data or select an available surrogate species.
    b. Review the online video, "A Tutorial on Field Procedures for Inventory and Assessment of Road-stream Crossings for Aquatic Organism Passage" and familiarize yourself with the necessary data sheets needed to conduct field work found in Clarkin et al. (2005), "National Inventory and Assessment Procedure – For Identifying Barriers to Aquatic Organism Passage at Road-Stream Crossings" found under "FishXing/AOP Documents" (right side of FishXing Homepage).

    Video Link: http://www.fs.fed.us/pnw/pep/PEP_inventory.html
    FishXing Homepage: http://www.stream.fs.fed.us/fishxing/
3. Collect necessary field equipment:
5. Conduct field assessments at road-stream crossings.
6. Inventory results in FS database.

Pros: More cost- and time-effective than other Level-2 assessments. Employs standard methods commonly used by Forest Service personnel. Appropriate for large-scale projects (watershed scale).

Cons: Not a direct measure of AOP. Limited number of species with detailed performance data (e.g., burst swim speeds, jump heights, etc.) available in the software.

Assumptions: Species performance data correctly predict performance given estimated hydraulic conditions.

Potential costs to consider: Personnel hours and survey equipment. Relatively inexpensive when compared to the other Level-2 assessments.

Example references: Clarkin et al. 2005.

Telemetry

Telemetry studies are a good way to monitor passability of road-stream crossings which give insight to timing of passage, physical conditions during passage, and characteristics of fish associated with passage (e.g., length, weight, etc.). While there are multiple forms of telemetry, including radio tagging (Winter et al. 2006) and acoustic telemetry (Steig et al. 2005), the most applicable to road crossing are the use of Passive Integrative Transponders (PIT) tagging combined with the use of in-stream antennae. Below, we describe the steps for using individual telemetry for evaluating AOP at potential barriers with reference to the published literature. Aarestrup et al. (2007) present a good study design for assessing individual movement at a bypass channel to a small dam. While not specific to road-stream crossings, the outlined process can easily be adjusted to measure AOP at road-stream crossing sites.

Similar to other forms of assessing AOP, using PIT tag telemetry requires a predetermined goal prior to implementing a study. In its simplest form, PIT tag telemetry can be used to determine if aquatic organisms are passing a potential barrier, regardless of passage efficiency. Data collected from PIT tag telemetry studies can be used to measure the percentage of marked fish that pass through a potential barrier, compare the passability of a road crossing to the surrounding natural stream reaches, or to conduct occupancy modeling.

Set up antennae – The first step involves determining the locations of antennae placement to detect aquatic organism passage (Figure 7). This process should consider locations where aquatic organisms enter, travel through, and exit a barrier, as well as a control location, preferably downstream of the barrier if circumstances allow. Things to consider: Water depth and detection probabilities, stability of antennae, and potential changes in flow.

Tagging and releasing fish – Aquatic organisms can be captured (via electrofishing or any other form of capture method), tagged, and released on the upstream and downstream ends of a potential barrier to detect multidirectional movement, or all be placed on one side of a potential barrier to increase the chances of detecting movement. Dunham et al. (2011) give a good explanation of this process.

Antennae upkeep - Once fish are marked with release-site specific tags, the remaining personnel power may be devoted to upkeep of antennae and the downloading of data.

When working with migratory species, additional antennae can be added downstream of the potential barrier in order to get a measure of how many individuals approach a potential barrier compared to how many actually pass.

Pros: Gives detailed information on individual fish regarding timing and speed (depending on monitoring process) of movements. Results regarding whether a barrier is passable are easy to interpret. Can elucidate species, behavior and length characteristics of fish passing through, or not, barriers (Lokteff et al. 2013). With a large enough sample size this approach can give good estimates of passage efficiency and determine if it is different for upstream versus downstream movement.

Cons: Requires a high rate of returns (scanned fish movements) to draw population-level implications. Without sufficient return data results are generally specific to individual fish. This approach can often underestimate passability because not all tagged fish will likely attempt to move past a given road crossing. Antenna scanning distance and flows can affect detectability.

Expensive at the catchment scale and can be difficult to obtain target species when population levels are low or are ESA-listed. Antennae can be damaged or destroyed during high water events. Personnel are required on a weekly basis to check power, download data, and/or check for potential vandalism.

Assumptions: All aquatic organisms that enter the study reach (pass one antenna) attempt to pass the second antenna and are not affected by the physically altered area surrounding a road-stream crossing. No aquatic organisms die of natural causes while attempting to pass through the study area.

Potential costs to consider: Passive integrated transponder (PIT) tags are inexpensive while antennas are expensive. Antenna installation generally requires specialized knowledge.

Example references: Aarestrup et al. 2003.

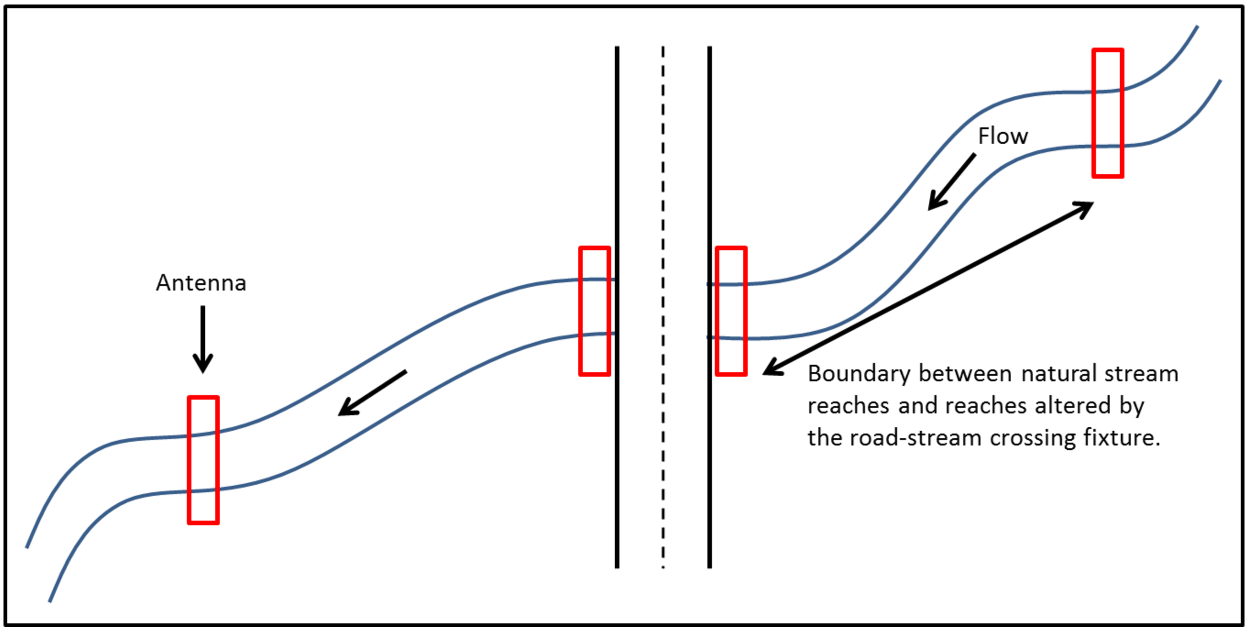

Figure 7. Example antenna placement for a PIT tag telemetry study. The value of this design is that it can assess both movement outside of the road-stream crossing and passability through the road-stream crossing. This makes it possible to draw comparisons between natural flow and the potentially obstructed crossing. Additionally, instead of placing the two outermost antennas as shown above, investigators can set two antennas in a downstream reach, out of the range of influence of the road-stream crossing, that measures aquatic organism movement which can be compared to movement through the crossing.

Mark-Recapture

Batch mark-recapture is a commonly used technique to identify movement through culverts and results from this type of study design can vary in complexity. In some cases, observing direct movement of individuals through a potential barrier may suffice, and in other cases, more detailed results may be necessary (occupancy modeling). Below we describe the techniques for assessing AOP through road-stream crossings using a batch mark-recapture study design, with direct reference to the published literature. Several studies have used batch mark-recapture to assess fish movement through culverts (e.g., Warren and Pardew 1998; Bouska and Paukert 2009; Norman et al. 2009). Additionally, Dunham et al. (2011) give a concise outline of sample design and the accompanying assumptions associated with batch mark-recapture studies.

The most basic sample designs for using mark-recapture for assessing AOP through culverts involve setting up sample reaches above and below the road-stream crossing of interest (see Dunham et al. 2011 for sample design) that will be sampled on multiple occasions. Additionally, control reaches may be added to the study design to assess AOP through culverts as compared to natural stream reaches (see Warren and Pardew 1998; Norman et al. 2009). Once sample reaches have been identified, an initial sample effort should be conducted via block electrofishing, seine netting, or another form of appropriate sampling for the species of interest. Individuals collected within each sample reach should be batch marked with fin clips, Floy tags, PIT tags, or any other form of marking that will allow the investigator the ability to identify the original marking area for an individual. Following the first sampling effort it is imperative that the investigators allow for enough time for the species to return to a mode of normal behavior, or in the case of detecting whether movement among migratory individuals has occurred, allow enough time for individuals to respond to the environmental queues that encourage migration. This may consist of allowing for 2 to 3 weeks to pass (Dunham et al. 2011), waiting for a flood event to occur, or for stream temperatures to queue spawning.

Following a period of time to allow for normal fish behavior, re-sampling at the same sites will allow for the identification of AOP through a potential barrier. As previously mentioned, results on the percentage of recaptured fish can be used to determine whether the species of interested is passing through the potential barrier, or a more thorough analysis will allow for the identification of factors that deter movement through the barrier.

In addition to detecting movement through culverts, batch mark-recapture studies can be used to identify road-stream crossing characteristics that deter movement using regression models. This is especially convenient because 1) after conducting the Level-1 assessment, physical features associated with the passability of a road-stream crossing will be readily available, and 2) these characteristics can be used later to better determine the passability of barriers that are region and species specific.

Pros: Can mark a large number of individual fish and species during one sample period with marks that are specific to distinct stream reaches. Results can vary from direct observation of fish movement to determining probability functions (detection, survival, and movement) for specific sites and species. Passability can be linked to characteristics of the road-stream crossings (e.g., flow, water depth, and crossing length) that occur between sample periods.

Cons: Fish may move beyond sample area during the time period between sampling. Typically recapture rates are less than 30% and it may be difficult to recapture fish which are present at low levels of abundance.

Assumptions: Environmental influences outside of the sample reaches (areas surrounding road-stream crossings) do not affect fish movement.

Potential costs to consider: Personnel hours and aquatic organism sampling equipment. Tags or marks can vary in price, but are relatively cheap compared to PIT tags.

Example references: Bouska and Paukert 2009; Norman et al. 2009; Dunham et al. 2011; Chelgren and Dunham 2015.

Abundance and Regression Models

Abundance and density estimates can be used in combination with regression analysis to detect factors that affect AOP. Abundance or density data collected from both upstream and downstream reaches of road-stream crossings can be used to develop statistical models that incorporate physical and/or biological characteristics of each of the road-stream crossings as predictor variables. An advantage of using regression analysis is that not only are specific road-stream crossings identified as locations with poor AOP, but specific features or culvert designs can be identified as having negative effects and those designs can then be avoided in the future. In addition to the approach just discussed, data collected from either batch mark re-capture studies or telemetry studies can be used to identify which factors affect AOP yet require more complex modeling (see Chelgren and Dunham unpublished). This regression approach, similar to other Level-2 assessments, depends on understanding assumptions regarding factors that potentially limit AOP of the species of interest; therefore, we suggest reviewing past literature regarding physical limitations to the species of interest.

Study design for modeling factors affecting AOP using regression analysis consists of setting up sample reaches located upstream and downstream of the road-stream crossings of interest. These sample areas should be relatively close to the crossings, but far enough away to avoid sampling habitat that is influenced by the road-stream crossing structure (Nislow et al. 2011 use a buffer 20 times that of the stream width). Following aquatic organism sampling (e.g., electrofishing, seining, trap netting), collect data on physical features outlined in the Level-1 assessment and additional physical or biological characteristics that may affect AOP based on your literature review of the species of concern. General guidelines for using regression analysis are taken from Nislow et al. (2011) and outlined below.

1. Identify barriers within catchment for assessment.
2. Determine which physical measurements to collect. For this step, we recommend reviewing the literature to understand which factors are potentially most important. Common physical parameters measured, which should be considered prior to any level one assessment, are outflow perch height, outflow pool depth, construction material, slope, length, flow, and water depth through the culvert.
3. Measure physical features following procedures outlined in Clarkin et al. (2005). Appendix E of Clarkin et al. (2005) gives excellent explanations of procedures for measuring physical features.
4. Set up fish sample design outlined in Nislow et al. (2011). If not sampling fish, review sampling methods for the desired species. Use block net, electrofishing in reaches upstream and downstream of each road-stream crossing.
5. Record fish data on length, weight, flow conditions, relationship to road-stream crossing (upstream or downstream).
6. Conduct statistical modeling using single species abundance or species diversity as dependent variables and independent physical features as predictor variables to determine which variables best predict the presence, absence, or density of fish above and below culverts. Be sure to account for downstream catch (i.e., if rainbow trout are not caught below a culvert, than they would likely not be above a culvert).

Pros: Can assess multiple species at once, specific to the drainage (models are not built from other data, outside of watershed and species), accounts for nested structure of dendritic systems, and represents a time-integrated assessment of passability (i.e., changes should manifest themselves over several years or generations)

Cons: May not represent true passability value (if sampled outside of optimum passability conditions, it may appear that the road-stream crossing has a low overall passability, when, in fact, the downstream reach may only be a staging area for crossing a potential barrier that actually has very high passability). The abundance of one species in relation to a given road-stream crossing may be affected by the abundance or presence of that same species at another crossing and this relationship may need to be accounted for statistically.

Assumptions: Only the variables collected or recorded in the field affect AOP.

Potential costs to consider: Personnel hours and field sampling equipment will be the primary costs, however, a large number of road-stream crossings ($n \geq 30$) will need to be sampled in order to obtain significant results.

Example references: Poplar-Jeffers et al. 2008 (uses ANOVA); Nislow et al. 2011.

Genetics

A newer approach for measuring fish movement employs the use of genetic markers that provide a method for detecting origins of an individual, often with little field time required, but requiring a researcher who can analyze and interpret genetic data. Genetic approaches are often used to detect aquatic organism populations with reduced gene diversity resulting from barriers restricting immigration to the target area. Depending on the study design, genetic data can be used to detect large movements over space and time that are otherwise difficult to describe with other techniques (Peacock and Ray 2001). In addition to detecting movement of individuals, genetic studies can be used to detect population-level metrics of health and gene diversity (Neville and Peterson 2014).

Neville and Peterson (2014) describe methods for using genetic data to describe the influences of potential barriers on fish at both the individual and population levels. While these techniques generally require less time in the field capturing and handling aquatic organisms, it does require more lab time and an investigator with the ability to analyze and interpret genetic data. Depending on the sampling design, genetic data can be used to answer questions about individual movement patterns or to look the impact of an aquatic organism passage barrier(s) on a population as a whole.

At the individual-scale and using genetic data from tissue samples, analyses exist that can allow managers to identify related individuals. This can be done by determining sibling individuals in unique families, and/or by assigning individual offspring back to their sampled parents (Hudy et al. 2010; Neville and Peterson 2014). These types of analyses estimate full-sibling families from samples collected throughout a study area (which can include single or multiple potential barriers) and use genotypes to define family boundaries in contrast to capture location. If individuals from the same family are found on both sides of a barrier, this can indicate movement across a barrier. However, it can be very difficult to determine directionality of the movement across the barrier. For example, if half of a group of identified full siblings are found on one side of the barrier and the other half are found on the other side, while this clearly shows that movement has occurred across the barrier, it is not possible to determine with these data if the movement was active and in an upstream direction, or occurred by passively being swept downstream across the barrier.

At the population scale, a number of metrics can be used to measure the effects of barriers on stream connectivity and proxies for aquatic organism passage. The population approach uses metrics such as gene diversity, allelic richness, and *M*-ratio, a characterization of how a population may have been affected by a genetic bottleneck or founder effects. One important factor to consider is how many years a potential barrier has reduced or eliminated stream connectivity, as it may take several to many generations for a genetic signal to develop depending on the population size on either side of the aquatic passage barrier.

An added bonus to the genetic approach is that both individual-scale and population-scale analyses can be performed from the collection of tissue samples. However, careful sampling design will be required based on the approaches one is taking. If an investigator is aiming to identify families, it will be best to sample juveniles, to increase the chance of sampling siblings. If the goal is to look at population level metrics, however, the investigator would want to sample *unrelated* individuals from the population. One could sample many individuals with the goal of doing both individual and population level analyses, but would need to sample enough individuals that related individuals could be removed from the population level analysis after they are identified.

Procedures for using a genetic approach:

1. Survey barrier locations using the coarse filter approach and determine which road-stream crossings may be barriers to AOP.
2. Consult a geneticist and determine the type of genetic analysis needed and the molecular markers to be used (microsatellites or Single Nucleotide Polymorphisms (SNP)). Analyses may include:
    a. Population level -- inference via genetic structure and gene diversity.
    b. Individual movement
        i. Sibling analysis –identify individual fish on either side of a crossing from the same family.
        ii. Parentage analysis – identify parents and their offspring.
        iii. Mark-recapture—repeatedly identify unique individuals through genetics to evaluate individual movement.
3. Select sample sites.
4. Collect fish (or other target organism) using electrofishing or other standardized sampling method.
5. Process tissue samples and analyze genetic data.

Pros: Gives time-integrated view of the effects of reduced connectivity through gene diversity. Can give results relevant to an individual road-stream crossing, or relevant to an entire species population, in relation to a number of crossings.

Cons: Requires someone with genetics expertise for sample design, analysis, and interpretation. Can't easily determine direction of fish passage, unless using mark-recapture methods. Age of barrier will have large effect on how strong a genetic signal can be detected using population level metrics. If the barrier is not very old, it is possible that a genetic signature of reduced connectivity would be undetectable.

Potential costs to consider: Collecting tissue samples is relatively cheap, but processing genetic samples can be costly and will require someone with genetic analysis experience.

Example references: Wofford et al. 2005; Neville et al. 2009; Hudy et al. 2010; Neville and Peterson 2014.

Things to Consider Prior to Getting Started

- How many road-stream crossings can be remediated?
- How many sites can be assessed using the Level-1 filter?
- How many sites should be assessed should be evaluated using FishXing and will the use of this Level-2 survey improve decisions?
- What unintended biological consequences could occur as a result of remediation? See McLaughlin et al. (2013).
- What unintended physical consequences could occur as a result of remediation?
- What AOP datasets already exist in the same region?
- Is there a coarse filter specific to the region of interest that is similar to those described within this protocol? If so, are they more species- and region-specific?

Choosing a Road-Stream Crossing Design for Remediation

While this guide is not intended to recommend structural designs for remediation the USDA Forest Service has a number of guides and references that cover this topic:

Stream Simulation: *An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings* can be found at www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm91_054564.pdf

The Forest Service has found that replacing undersized culverts with a stream simulation-designed structure provides both flood resilience and aquatic organism passage and reduces the risk of adverse impacts to communities and businesses caused by flood damage and catastrophic failure of road-stream crossings. Stream simulation design is an ecologically-beneficial approach to road-stream crossings that creates a natural and dynamic channel through the crossing structure similar in dimensions and characteristics to the adjacent, natural channel and allows for unimpeded aquatic organism passage during various flow conditions. Stream simulation-designed structures have proved to provide long-term ecological and flood resiliency benefits to the agency and surrounding communities, including a lower risk of road-stream crossing failure and sediment delivery into the stream, longer structure life cycles, and reduced spending on disaster recovery. When choosing a road-stream crossing for remediation, it may be important to consider social and long-term economic benefits to surrounding communities in addition to ecological benefits to the aquatic ecosystem.

Case Study: Daniel Boone National Forest, Kentucky

Objective:

Determine the aquatic passability of a subset of 20 road-stream crossings, including 2 road-stream crossings with planned upgrades for AOP, across the Daniel Boone National Forest to compare various methods for effectively monitoring fish movement, determining effectiveness of planned AOP projects, and prioritize barriers for remediation and/or replacement.

Steps taken:

- The Daniel Boone National Forest in Kentucky contracted the Center for Aquatic Technology Transfer to rate the aquatic passability of 850 road-stream crossings across the Forest using the Level 1 Coarse Filter Analysis.
- 20 sites with varying perceived degrees of aquatic organism passability were chosen for a range of AOP effective monitoring techniques.
- In order to compare and assess the most effective method(s) to determine whether a road-stream crossing presented an actual barrier to upstream connectivity, the following methods were applied:
    - At all 20 sites mark-recapture was performed using fin clips of an abundant fish with poor jumping and moderate swimming ability.
    - At 3 sites telemetry was used with PIT tags and stationary antennas above (1 set of antennae) and below (2 sets of antennae) road-stream crossings.
    - At 7 sites genetics analyses were performed, using sibling analysis monitoring.

Results:

- Mark-recapture of creek chub (a common minnow species) using fin clips proved to be very poor at the reference sites below the culverts (between 2% and 12% recapture rate) and no meaningful conclusions could be drawn as to the relative passability of any given road-stream crossing.
- Standard PIT tag telemetry and stationary antennae showed high rates of movement through "Green-easy passage" culverts at 42% of tagged individual fish, 20% of tagged individuals moving through "Gray-moderate passage" culverts, and 0% of individuals moving through "Red-difficult passage" culverts.
- Genetic sibling analyses suggested that percentage families with siblings on both sides of the culvert, indicating movement across the culvert, is higher for "Green" versus "Red" culverts. However, additional sampling is needed, particularly from reference streams where a natural barrier such as an impassable waterfall exists to provide a baseline of genetic information and connectivity between naturally isolated populations.

Conclusions:

- Project results suggest that PIT tag telemetry using stationary antennae provides the most reliable estimates of successful movement and direction of movement through culverts. Note that determining upstream direction movement of aquatic organisms across a potential barrier is critical.
- Mark-recapture methods via fin clips provides very little information, due to the high number of samples required and low recapture rate.

- Genetic techniques require less field time, and allow a general sense of movement across a barrier, but necessitate more background study to contextualize findings. Additionally, it is very difficult to determine directionality of passage with high certainty.
- Level-2 surveys often yield equivocal results of passability. Probably should replace pipes labeled grey and red using Level-1 surveys if habitat above site is meaningful.


Figure 8: (On left): Mark-recapture of individual fish using backpack electroshocking.
Figure 9: (On right): Stationary Antenna PIT tag monitoring at a "Gray-moderate" road-stream crossing.
Credit: Craig Roghair, Center for Aquatic Technology Transfer, USFS

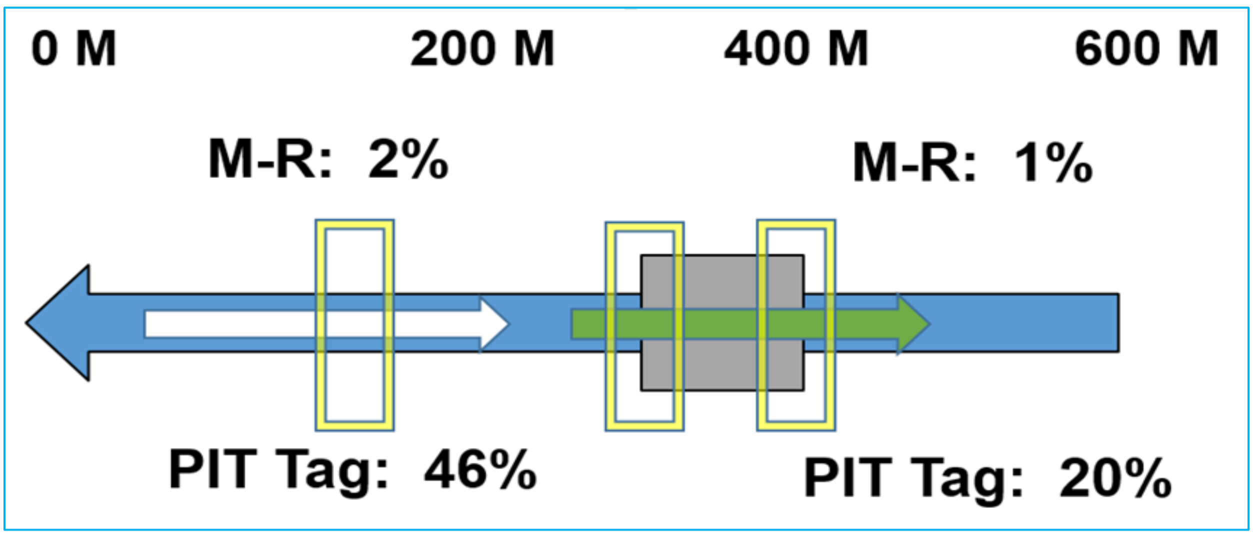

Figure 10: *This diagram illustrates the comparison of the mark-recapture of fin-clipped Creek Chub versus the PIT telemetry method to monitor aquatic organism passage of through a "Gray" culvert with moderate passage. The flow of the stream is right to left as designated by the blue arrow. At the downstream reference reach between 0 and 200 meters (white arrow), the mark-recapture method yielded a 2% recapture rate of marked individual fish at the reference reach (white arrow) downstream of the culvert, and only 1% recapture rate through the crossing between the 300 and 500 meter section (green arrow). In comparison, the PIT Tag Telemetry method using Stationary Antennas (yellow boxes) achieved a 46% recapture rate in the downstream reference reach (white arrow), and a 20% recapture rate upstream of the culvert (green arrow). The PIT Tag Telemetry method provides clear evidence that this "Gray - moderate Passage" culvert does indeed provide some level of aquatic organism passage in the downstream to upstream direction.*

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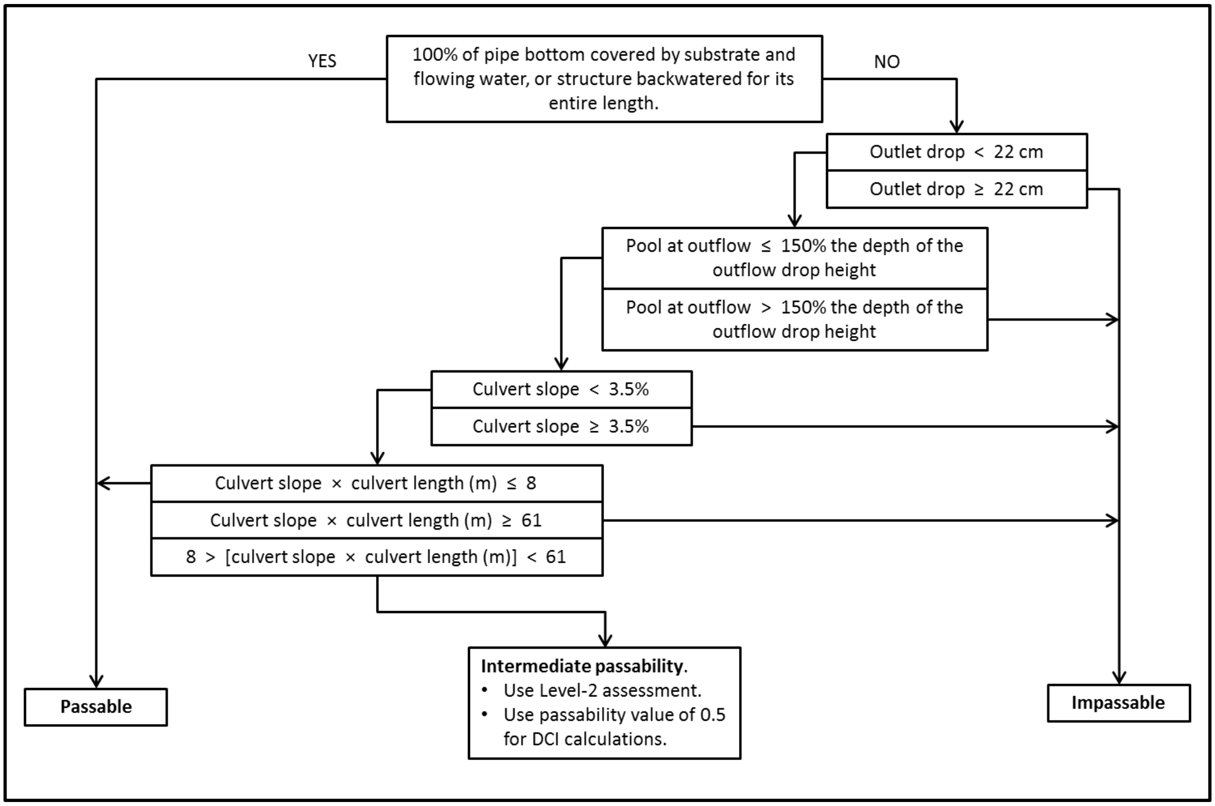
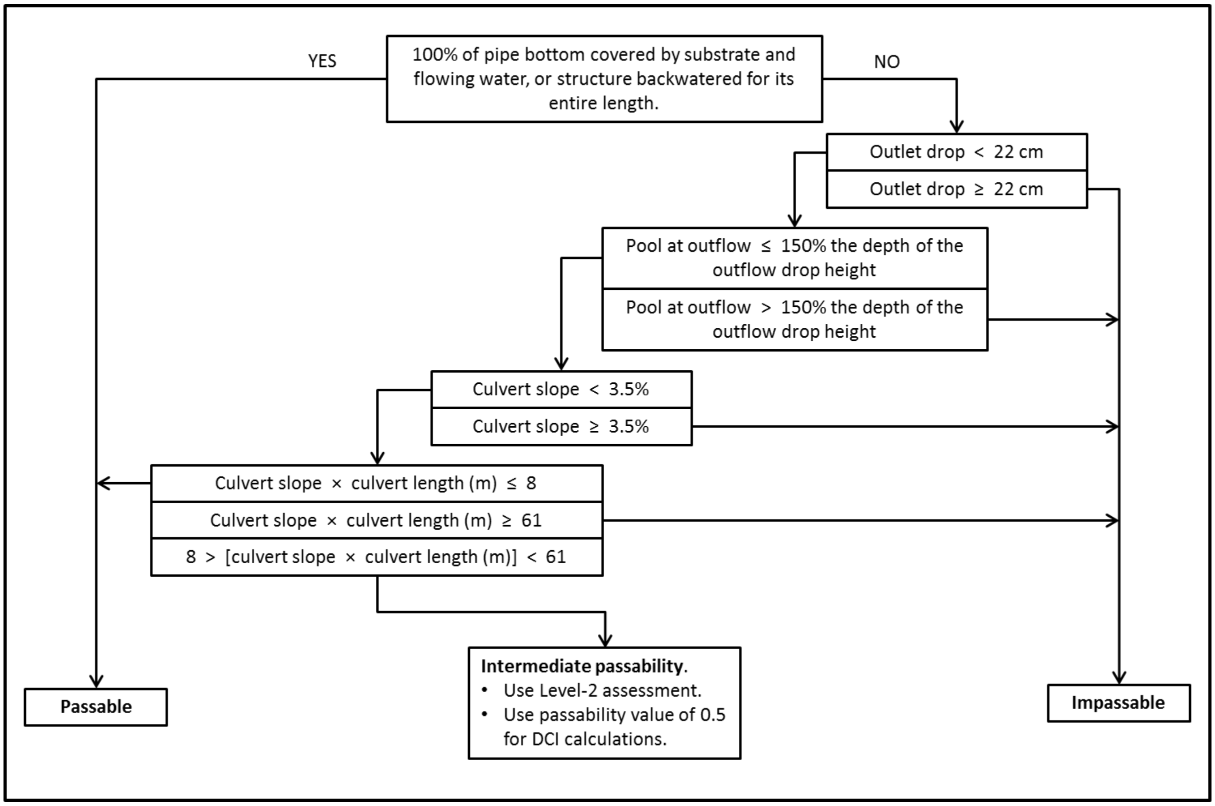
Appendix: Level-1 Coarse Filter for Young-of-the-Year Salmonids and Cyprinids



Default Level-1 Coarse Filter for young-of-the-year salmonids and cyprinids. Flow chart is modified from those developed in Coffman et al. (2005) and Bourne et al. (2011). This filter serves as a starting point in the absence of site specific data.



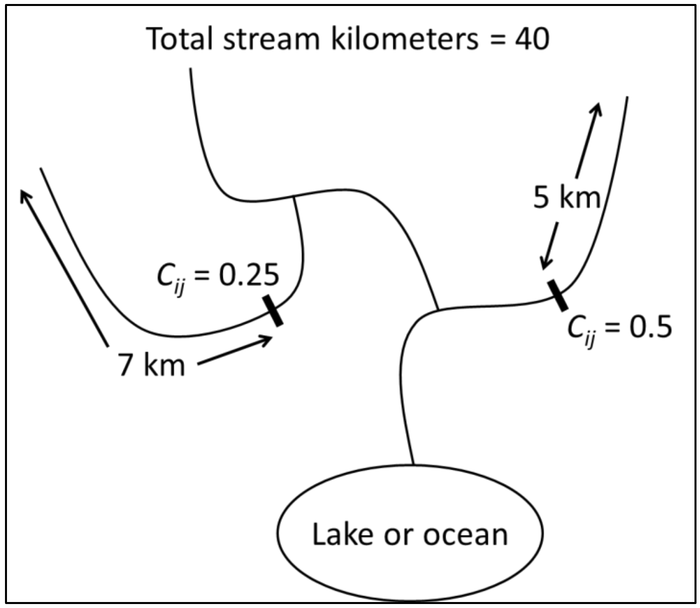
Level-1 Coarse Filter for percids and cottids. Flow chart is modified from those developed in Coffman et al. (2005) and Bourne et al. (2011). This filter serves as a starting point in the absence of site specific data.

Level-1 Coarse Filter Data Sheet

Date ___________________________ Crew ____________________________ Project _________________________
Forest ______________________________ District _________________________________Watershed (6) HUC or Name___________________

Culvert ID	GPS Coordinates (or other location info)	Natural substrate or backwatered throughout? (Yes/No)	Outlet drop height (cm)	Pool depth at outflow (cm)?	Pool at outflow/outlet perch height	Culvert Slope (%)	Culvert Length (m)	Culvert slope (%) × length (m)	Passable? Unknown? Impassable?	Comments

DCI Example



The following steps describe how to calculate DCI_D and DCI_P for Figure A-1.

where l_i is length of stream segment i, L L is the total stream length of the system,

and and are the upstream and downstream passabilities of barrier m, respectively. To calculate DCI_D in this

example, treat C_{ij} equal to (note:

C_{ij} depends on the value of and may change depending on the direction of movement – we treat upstream and downstream passability the same in this example) and remember that DCI_D is calculated in reference to the downstream end, closest to the lake or ocean, so passability to the middle segment (l_m) is 1 (C_{mm}), passability to the left-hand segment (l_l) is 0.25 (C_{ml}), and passability to the right-hand segment (l_r) is 0.5 (C_{mr}). The calculation is conducted as:

To calculate DCI_P, again, treat C_{ij} equal to and multiply the passability value(s) by the proportion of stream lengths being considered. Note: the passability values for each segment may be the product of multiple barriers crossed to reach each segment. See below for an example:

$$
\begin{aligned}
DCI_P = & \Big(\frac{l_l}{L}\frac{l_l}{L}(p_l^u p_l^d) + \frac{l_l}{L}\frac{l_m}{L}(p_l^u p_m^d) + \frac{l_l}{L}\frac{l_r}{L}(p_l^u p_r^d) + \frac{l_m}{L}\frac{l_m}{L}(p_m^u p_m^d) + \frac{l_m}{L}\frac{l_l}{L}(p_m^u p_l^d) \\
& + \frac{l_m}{L}\frac{l_r}{L}(p_m^u p_r^d) + \frac{l_r}{L}\frac{l_r}{L}(p_r^u p_r^d) + \frac{l_r}{L}\frac{l_m}{L}(p_r^u p_m^d) + \frac{l_r}{L}\frac{l_l}{L}(p_r^u p_l^d)\Big) \times 100 \\
= & \Big(\frac{7}{40}\frac{7}{40}(1) + \frac{7}{40}\frac{28}{40}(0.25) + \frac{7}{40}\frac{5}{40}(0.125) + \frac{28}{40}\frac{28}{40}(1) + \frac{28}{40}\frac{7}{40}(0.25) \\
& + \frac{28}{40}\frac{5}{40}(0.5) + \frac{5}{40}\frac{5}{40}(1) + \frac{5}{40}\frac{28}{40}(0.5) + \frac{5}{40}\frac{7}{40}(0.125)\Big) \times 100 = 68.7
\end{aligned}
$$

Note: while the above example contains no habitat quality component, we recognize that a habitat quality parameter (H_q) could easily be added to each reach by multiplying by the passability coefficients. This parameter would need to be scaled from 0-1. We caution that because the addition of a habitat quality component would be multiplicative, adding such a component could have a disproportionately large effect on the overall results. We therefore suggest that any stream with perennial or consistent flow during times important for spawning and maturation should be given a value of at least 0.5. Any moderately good habitat should be assigned a value of 0.75 to 1

Now that dendritic connectivity values are calculated, one can modify passability values to assess how remediation efforts will affect stream connectivity.