RESTORING STREAM CONNECTIVITY IN VIRGINIA

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Problem statement

Longitudinal connectivity of streams is critical for the persistence of populations of fish and other aquatic wildlife such as turtles and salamanders. All the resources and conditions an animal needs to survive and complete its life cycle are rarely met in a single place. Fish require access to *complementary habitats* (e.g., suitable feeding, spawning, and hiding areas) to successfully pass through each life stage from embryo to adult, and as environmental conditions change seasonally. Furthermore, stream fish require access to *supplementary habitats* in order to persist in a shifting riverscape where periodic disturbances, both natural and human, may alter any given habitat unit (e.g., a pool may be filled with sediment during a flood, or a stream section may be degraded by riparian deforestation). While destroying habitat in one place, a dynamic stream creates new supplemental habitats elsewhere in the stream network, but these can be colonized only if they are accessible. Movement of individuals between distant populations may also be required to limit inbreeding, which reduces the fitness and resilience of isolated populations through the increase of deleterious traits. Thus, aquatic biota may need to move up- or downstream to access complementary and supplementary habitats and for populations to interbreed.

A high proportion of road culverts fragment streams, disconnecting populations of aquatic animals from each other and from their crucial complementary and supplementary habitats. When designed with the sole objective of transporting water and vehicles (and perhaps sediment), culverts often block or limit longitudinal movements (especially upstream, but also downstream—see Benton et al. 2008) of stream fish. Hotchkiss & Frei (2007) identified seven common characteristics of road culverts that can limit fish passage: 1. drop at culvert outlet; 2. inadequate outlet-pool depth; 3. excessive velocity; 4. insufficient depth; 5. excessive turbulence; 6. debris accumulation; or 7. behavioral barriers. Culverts are extremely common because the road network is so dense[1], and culverts are considered more cost effective than bridges.

Although studies are sparse for the eastern U.S., the fish-passage literature provides strong evidence of restricted movement of fish through culverts, and resulting impacts to fish communities. By marking many individual fish and comparing their frequency of movement through different types of road crossings, Benton et al. (2008) and Briggs & Galarowicz (2013) provided direct evidence of reduced movement through culverts, even including some non-perched culverts in low-gradient streams (Briggs & Galarowicz 2013). Coffman et al. (2005) and Poplar-Jeffers et al. (2009) surveyed many culverts in the West Virginia and Virginia mountains and estimated the relative "passability" of each culvert based on criteria known to limit upstream fish passage. Coffman et al. (2005) estimated that 37%, 71%, and 80% of culverts in the George Washington and Jefferson national forests (VA) were impassable to strong, moderate, and weak swimmers, respectively. Poplar-Jeffers et al. (2009) estimated that 69% of state-owned culverts in the upper Cheat River drainage (WV) were completely impassable to even the strongest swimmers (adult trout). Nislow et al. (2011) compared the fish assemblages upstream and downstream of predicted-impassable culverts in the upper Greenbrier River drainage (WV) and found that reaches located upstream of culverts had less than half the total fish abundance and number of species compared to downstream reaches.

[1] For example, in the Virginia portion of the New River drainage, there is an average of one road crossing for every 700 m of stream length, based on the intersection of the National Hydrography Dataset (NHD) Plus version 2 streams GIS layer with a 2010 U.S. Census roads layer.

The U.S. Army Corps of Engineers (COE) regulates the installation or replacement of culverts in all waters of the United States. COE nationwide permits include the requirement to sustain movements of aquatic species[2] (not just fish). At the state level, the Virginia Department of Transportation (VDOT) requires that road culverts "be designed to accommodate the passage of fish"[3]. However, from the studies cited above, it is evident that many existing culverts interrupt stream connectivity and are not scheduled for replacement in the near future.

Furthermore, VDOT's current design standards for new or replacement culverts are inadequate to meet the COE's, and even VDOT's own fish-passage requirements. VDOT apparently adopted their current culvert-design standards from a single, outdated, in-house literature review (Fitch 1995) that recommended culvert flow velocity should not exceed 1.2 m/s, which was considered to be the critical swimming speed of the strongest swimmers (adult trout). Therefore VDOT's design standards do not ensure passage for weaker swimming fishes. For example, Gardner (2006) demonstrated much lower critical velocities (0.37–0.86 m/s) for six fishes chosen to represent the variety of morphologies common to the North Carolina Piedmont. Furthermore, about 60 aquatic species other than fish, including amphibians, reptiles, mammals, mussels, snails, crustaceans, and insects, have special legal status in Virginia[4]. Habitat fragmentation due to culverts is likely among the causes of imperilment for many of these species (e.g., salamanders, see Anderson et al. 2014). Clearly, any solution to restoring stream connectivity in Virginia must begin by targeting VDOT's unsatisfactory culvert design standards.

Strategy to restore stream connectivity

Inadequate culvert design standards are the root cause of Virginia's fragmented streams. VDOT could implement the changes needed to fix the problem; however, since VDOT's core mission and expertise is focused on moving people and goods, the Commissioner will not likely take it upon himself to make substantive changes on behalf of fish. Rather, he will need to be directed to do so by Virginia's elected officials, in particular the Governor, who appoints commissioners. In short, a champion statesman is needed to raise the issue of stream connectivity at the highest level of Virginia's government. But the statesman will require strong backing in the form of a stream-connectivity stakeholder coalition (SCSC) comprised of concerned citizens, corporations, watershed and environmental groups, VDOT engineers, Virginia Department of Game and Inland Fisheries (VDGIF) biologists, and stream-connectivity experts who are committed to the conservation of diverse non-game species.

The first task of the SCSC would be to develop comprehensive culvert design standards to be implemented by VDOT. In order to ensure that the proposed standards provide passage for all aquatic fauna, the SCSC would advocate for a geomorphic-simulation approach to culvert

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[2] Nationwide permit general conditions.–Aquatic Life Movements: "No activity may substantially disrupt the necessary life cycle movements of those species of aquatic life indigenous to the waterbody… All permanent and temporary crossings of waterbodies shall be suitably culverted, bridged, or otherwise designed and constructed to maintain low flows to sustain the movement of those aquatic species." *Source:* COE. 2012 nationwide permits Federal Register notice (corrections) – 21 September 2012. Available: http://www.usace.army.mil/missions/civilworks/regulatoryprogramandpermits/nationwidepermits.aspx

[3] "In areas of known fish habitat, highway culverts are to be designed to accommodate the passage of fish..." *Source:* Drainage design memorandum DDM 1 (drainage instructions). Chapter 15 *In:* VDOT drainage manual. Available: http://www.virginiadot.org/business/locdes/hydra-drainage-manual.asp.

[4] *Source:* http://www.dgif.virginia.gov/wildlife/virginiatescspecies.pdf

design, rather than the current hydraulic-design approach that targets a few hydraulic conditions (e.g., maximum velocity <1.2 m/s, no hydraulic jump) to meet specific needs of a single focal species and life stage (adult trout). The geomorphic-simulation approach maintains connectivity for all aquatic species by matching natural channel conditions (e.g., ≥bankfull width, natural substrate, mobile bed, unaltered hydraulics for flows to slightly above bankfull) within the culvert crossing (Hotchkiss & Frei 2007). The SCSC would sponsor a culvert-design research symposium to become more informed of the different design approaches and applications of the geomorphic-simulation approach implemented by other jurisdictions.

While VDOT has the infrastructure and expertise to design and build culverts and bridges to meet the updated design standards, a technical team of conservation biologists, ecologists, and GIS and database specialists would be needed to identify and prioritize restoration projects based on the greatest conservation needs. To fill this role, the SCSC would advocate for, and if necessary contribute funding toward, an expansion of VDGIF's existing Fish Passage Program (FPP) to include all aquatic species statewide. The FPP is currently focused on restoring fish passage in anadromous waters of the Chesapeake Bay watershed via dam removal and remediation. The primary roles of the expanded FPP would be to: 1. adopt a culvert inventory and assessment protocol and database to identify impassible culverts; 2. coordinate culvert surveys; 3. adopt a decision-support system to prioritize watersheds and individual impassable culverts for restoration; and 4. develop partnerships and apply for funding to implement high-priority projects.

It is VDOT's responsibility to install compliant crossings. This responsibility will not change when Virginia's culvert design standards are updated to attain compliance with federal and state stream-connectivity regulations. Therefore, the bulk of the costs to expand the FPP and install compliant culverts and bridges would be paid from VDOT's highway construction program. However, projects requiring stream mitigation under the COE regulatory program and the Virginia Department of Environmental Quality's (VDEQ) Virginia Water Protection Permit Program would be another potentially major source of funding for restoring stream connectivity in Virginia. The COE and VDEQ's Unified Stream Methodology (USM) manual[5] describes the method used to assess stream-compensation requirements for permitted stream impacts. The USM lists various stream-compensation practices, including improvements to culverts and bridges, which may be implemented to compensate for unavoidable impacts to streams. Other potential sources of matching funds for restoring stream connectivity include the Virginia Fish Passage Grant and Revolving Loan Fund (§ 29.1-101.2), the National Fish Passage Program, conservation non-profits such as Trout Unlimited and The Nature Conservancy, and corporate sponsors seeking to demonstrate environmental stewardship.

In conclusion, stream crossings can be designed to allow for the free passage of aquatic species, as is required by COE and VDOT regulations, but many of Virginia's legacy culverts impede passage, and VDOT's current inadequate culvert design standards ensure the impassibility of many newly installed culverts. Compared to other less tractable and diffuse stressors contributing to the decline of aquatic species (e.g., widespread habitat loss, non-point-source pollution, harmful introduced species, climate change), stream fragmentation has a clear and specific root cause and a straightforward remedy that is within reach. Fixing

[5] *Available:* http://www.deq.virginia.gov/Programs/Water/WetlandsStreams/Mitigation.aspx (accessed 21 November 2014)

impassable culverts is the single most cost-effective way to quickly bolster the resilience of Virginia's stream ecosystems and recover declining aquatic species.

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