Final Report on Barriers to Aquatic Organism Passage in the Upper Little Tennessee River Basin

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Introduction

The focus of this project was to assess stream crossings within the Upper Little Tennessee River basin from the NC/GA state line to the town of Franklin (excluding tributaries directly entering the lacustrine system of Lake Emory). The purpose for this project was to continue with a previous assessment conducted in 2007 by U.S. Fish and Wildlife Service whose focus was on the section downstream from Lake Emory to Fontana Reservoir. Recent studies in the southeastern United States have demonstrated that culverted road crossings can be significant barriers to the movement of aquatic organisms, especially small-bodied fish (Millington, 2004; US Forest Service, 2005).

In late 2010, the Little Tennessee Watershed Association invited a collaborative team (see box to right) of federal, state, and local partners and began a study to determine the significance of road and driveway crossings in impeding small-bodied fish movement on tributaries draining 190 mi^2 of the upper Little Tennessee River. In a general sense, it is always desirable to eliminate anthropogenic barriers to free movement of fish up and down streams. It is well documented that numerous species of fish move between mainstem rivers and tributaries for various reasons, including access to spawning sites, nursery areas, summer refugia, and predatory sorties by piscivores. In the specific case of the Little Tennessee, beginning in 1999 we documented mass fall migrations between tributary streams and the mainstem river by a variety of species, most notably the whitetail shiner (*Cyprinella galactura)*, telescope shiner (*Notropis telescopus*), warpaint shiner (*Luxilus coccogenis*) and the federally Threatened (NC endangered) spotfin chub (*Erimonax monachus)* (McLarney, 2007). While the spofin chub is absent from the watershed upstream of Franklin, NC the apparent biomass of fish, particularly the whitetail shiner, moving up and down tributary streams in the fall suggests an important, though as yet not understood, function of these migrations in maintaining biotic integrity in the larger system. It should also be noted that, while the spotfin chub is absent, the upper watershed does host a number of listed aquatic species of concern in the State Wildlife Action Plan (NCWRC, 2005) that inhabit the sampled reach, including: smoky dace (*Clinostomus spp*.), mountain brook lamprey (*Ichthyomyzon greeleyi*), olive darter (*Percina squamata*), brook trout (*Salvelinus fontinalis*), Little Tennessee River crayfish (*Cambarus georgiae*), hellbender (*Cryptobranchus alleganiensis*), common mudpuppy (*Necturus maculosus*).

Study Participants:
- US Fish and Wildlife Service
- Ecosystem Enhancement Program
- NC Department of Transportation
- Watershed Science, Inc.
- Western Carolina University
- Wildlife Resources Commission

The objectives of this study were (1) to identify crossings that are impassable to native fish and (2) to prioritize crossings for replacement. The team elected to examine all public and private road crossings as well as any other known anthropogenic barriers (old mill dams, etc.) on streams with a drainage area of at least two square miles. The first phase of this study, performed in fall 2010, was the physical assessment of the crossings. The second phase of this study, performed by qualified staff biologists led by Dr. Bill McLarney during fall 2011, documents fish communities above and below a subset of the crossings to test assumptions on crossing passability and prioritize crossings for replacement.

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Methods

Study area

The study area included tributaries that empty into the Little Tennessee River between the North Carolina/Georgia state line and Lake Emory (Figure 1). We emphasized tributary streams with a watershed area of at least 2 mi^2, below which size we have observed that natural fish diversity drops sharply. However, a few sites on smaller streams were included where we identified potential anthropogenic barriers near the mouth of the stream, and generally a direct tributary to the mainstem.

Each site was assigned a site code, identified and described by: stream name, road name, state road number, road type (paved/gravel), crossing ownership (private/state-owned), and structure type (corrugated pipe/ concrete box).

Phase 1 field methods

Each crossing was initially assessed by a technical staff person to determine if a detailed physical survey was needed. Most bridges, fords, and embedded culverts with adequate water depth and little increase in velocity were deemed passable and excluded from a detailed physical survey. The crossing type was described and its locality determined with a GPS unit. A subset of existing natural barriers (waterfalls and beaver dams) were also located and described. A detailed physical survey was performed on crossings that were not determined to be passable using the visual assessment.

The US Forest Service's 2005 National Inventory and Assessment Procedure for Identifying Barriers to Aquatic Organism Passage at Road-Stream Crossings was modified for use in this study. Field methods and data collection were completed according to the methods described by Leslie (2008). Information collected included: Elevations of the culvert inlet, culvert outlet, water surface, and tailwater control, stream and riparian habitat, local channel instability, crossing type, dimensions, and substrate, and a sketch of the crossing and its surroundings (see Appendix). Photos were taken of the crossing, along with upstream and downstream views for reference purposes.

Data analysis

Passability was determined using predictive models for fish swimming and leaping ability used by the US Forest Service staff of the Forests of North Carolina, which were based on models developed and tested by Clarkin et al. (2003) and Coffman (2005) (Figures 2 and 3). Two models were used—model "B", which applies to moderate swimmers/leapers, such as cyprinid species and juvenile trout, and model "C", which applies to weak swimmers/leapers, such as darters and sculpins. The following four metrics were considered when determining passability:

(1) Pipe fully backwatered or covered by substrate
(2) Drop; if no tailwater control, then perch was used
(3) Structure slope
(4) Structure slope x length

In this study, the drop metric was sometimes not applicable, as at some sites there was no definitive pool below the crossing. The drop was only used to determine impassabilty if the perch (the difference in elevation between the structure outlet and the water surface below the outlet) was positive and was also above its impassability threshold. All structures evaluated through these models were deemed passable, impassable, or indeterminate.

Phase 2 field methods
Fish samples were carried out up and downstream of any structures selected for Phase 2 methods by qualified technical persons. Structures deemed impassable or indeterminate were evaluated on distance to the mainstem river or large tributary (Cullasaja River, Cartoogechaye Creek), and the drainage area above the structure, and any other identified barriers along the stream. This allowed us to prioritize where to monitor fall migrations. Indeterminate structures, close proximity to the mainstem, large upstream drainage area, and no other identified barriers received a higher priority.

Native species of interest include two groups, fall upstream migrants and river-dependent species which have been documented from tributaries in the study area. Fall upstream migrants show clearly defined movement up tributary streams from the Little Tennessee River in the fall, and are considered the primary indicators of barrier passability in this study. The only species categorized as a fall upstream migrant for the mainstem reach (i.e. NC/GA state line to Franklin) included in this study is the whitetail shiner. Whitetail shiner was treated as the primary "indicator species" in this study.

River-dependent species are those found in both tributary streams and the river mainstem, but for which there is no clear upstream migratory pattern in the fall. While some of these species may be found above "impassable" barriers in larger streams, all seem to require communication between the mainstem and tributary systems for population maintenance. These species include: mountain brook lamprey, central stoneroller (*Campostoma anomala*), warpaint shiner, river chub (*Nocomis micropogon*), Tennessee shiner (*Notropis leuciodus*), mirror shiner (*Notropis spectrunculus*), fatlips minnow (*Phenacobius crassilabrum*), white sucker (*Catostomus commersoni*), northern hogsucker (*Hypentelium nigricans*), black redhorse (*Moxostoma duquesnei*), golden redhorse (*Moxostoma erythrurum*), rock bass (*Ambloplites rupestris*), smallmouth bass (*Micropterus dolomieu*), Tuckasegee darter (*Etheostoma gutselli*), greenfin darter (*Etheostoma chlorobranchium*), gilt darter (*Percina evides*), and olive darter. Presence of these species in our fall samples, or in summer or fall samples from previous years, was treated as a secondary indicator of barrier passability.

Yet another clue to barrier effectiveness is provided by the exotic yellowfin shiner (*Notropis lutipinnis*). This species, native to neighboring Atlantic and Gulf Coast drainages, was first identified from the Little Tennessee watershed in 1989 (personal communication, Charles Saylor, TVA) from a site near the Georgia/North Carolina state line and has subsequently spread downstream in the mainstem and upstream along tributaries (McLarney 1995, 1997, 2003). Barring additional introductions, the presence of this relatively weak-swimming cyprinid above a barrier candidate site should be taken as evidence of passability for cyprinids (Filter B).

Fall sampling was initiated once visual observation confirmed that groups of whitetail shiners (normally absent or nearly absent from all tributaries during the summer) had entered the tributaries. All sites were sampled using essentially the same methods, with the up and downstream pair samples on the same day. Each reach was sampled by a 2 person team using a backpack electrofisher and dipnets. The usual procedure was to proceed upstream, covering optimal habitats (pools). Captured fish were placed in buckets until a particular habitat unit was completed, then identified, counted and released downstream of the sampled area, so as to prevent recapture and double counting.

While we attempted to capture all fish seen, there was undoubtedly a bias toward silvery, fusiform species, since these were the principal targets of the survey. In an effort to minimize stress and mortality, we used the lowest feasible voltage and did not attempt to approach depletion as in IBI samples or faunal inventories.

If habitat just up- or downstream of the crossing seemed poor, we would sample additional pools until a reasonable capture rate was achieved, or we were convinced that the habitat was inadequate. In some instances, culvert placement has resulted in large, deep, round scour pools with eddying currents. In these environments, multiple passes of the electrofisher were needed to achieve a reasonable capture rate, though depletion was not approached.

Prioritization
Structures were prioritized for replacement or retrofitting following the fish community assessment. A meeting was held with partners to help with prioritization. Prioritization was based upon criteria such as: distance to the mainstem (Little Tennessee River, Cullasaja River, or Cartoogechaye Creek), drainage area above barrier, presence of natural barriers, presence of additional anthropogenic barriers, elevation, relative cost, and species affected by action or no action.

Results
An initial stream crossing assessment was conducted using a GIS analysis of all stream crossings on the Little Tennessee River and its tributaries (drainage area >2 mi^2) between the NC/GA state line and Lake Emory during August 2010. We identified and assessed 157 stream crossing and/or structures for passability, covering approximately 200 miles of stream. Most of these structures (115) were not subjected to a detailed physical survey because they were judged passable by visual assessment.

Phase 1, physical survey
Physical survey assessments were conducted during November 2010. Of the 42 structures that required a physical survey, 30 were corrugated pipe culverts, 5 were box culverts, 5 were dam remnants, and 2 were other structure types. Only culverts were analyzed for passability using predictive models for fish passage (Figures 2 and 3; Table 1). Of these, 15 were deemed impassable and 7 were indeterminate for filter B (i.e. shiners), whereas 18 were impassable and 6 indeterminate for filter C (weak swimmers) (Figures 4, 5, 6).

Phase 2, fish survey
The tributary watersheds taken into account in this project have all been the subject of varying amounts of summer and fall fish survey work by the Biomonitoring Project Team during 1990-2011. Local fish migrations are triggered by environmental conditions, relatively unknown to us. Beginning in October 2011, we undertook periodic sampling of Little Tennessee tributaries lacking anthropogenic barriers to determine the onset of the fall migration. Once significant numbers of whitetail shiners were determined to be moving into these streams, sampling was initiated on the project sites.

We were able to assess 14 of the 24 indeterminate and impassable sites (Table 2; Figures 4, 5, 6) for passability, using the whitetail shiner as our primary "indicator species" for fall upstream migration. However, each stream has different characteristics, both natural and anthropogenic and may be more or less preferred by whitetail shiners. While we are fairly confident in our explanation for the lack or low abundance of whitetail shiners in some situations (poor habitat, high elevation, etc.), other times we are less certain. Therefore, incorporating data from other "river-dependent" species and/or the invasive yellowfin shiner helped to provide further circumstantial evidence for passability. The results for each stream are as follows:

Mashburn Branch

The potential barrier selected for evaluation on Mashburn Branch (CUL-MAS-A) is located on Fulton Rd. (SR 1668) less than 0.1 mi. above the Cullasaja River. Visual inspection of the site revealed that, independently of the characteristics of the pipe culvert which constitutes CUL-MAS-A, it is a poor site for sampling. There was some pool structure downstream of Fulton Rd. but, although pool depth was not measured, the bottom of all the pools was covered with unstable sand, and maximum depth appeared to be less than 1 foot. Upstream of the road for several hundred yards the habitat was composed of rubble/cobble riffles with occasional small pocket pools. It appeared probable that even if whitetail shiners or other migratory fish did pass through CUL-MAS-A, resting time near the site would be minimal and thus the probability of capture of significant quantities would be minimal.

However, IBI sampling of Mashburn Branch further upstream had revealed the presence of a large, deep (2.9 ft. maximum) pool at RM 0.8, where a private gravel road (Schley Farm Road) passes through an undersized tube culvert. We reasoned that if fall migrant fish were found there it would obviate the need for sampling near the culvert, above or below.

In the course of 5 IBI samples carried out during 1996-2001 on a reach of Mashburn Branch which had its upper end at Schley Farm Rd., we encountered 10 species of fish (8 native), which included no shiners or other presumptive migrants. Smoky dace were very rare (3 individuals in the 5 samples) and other cyprinids were sedentary forms. In contrast, the 2011 fall sample produced 67.2% shiners, 41.4% whitetail shiners and also 8 smoky dace. One juvenile black redhorse was also taken. On the basis of this sample we conclude that CUL-MAS-A is fully passable by migratory cyprinids.

This leaves open the question of whether the culvert at Schley Farm Rd. constitutes a barrier itself. We also noted a bedrock ledge located about 50 ft. above Schley Farm Rd. with about a 1 ft. vertical drop, which might function as a natural barrier. There was little significant deep water habitat between the road and the ledge, so we elected to sample two pools above the ledge.

The results (3 native species, with no likely migrants) suggest that the culvert and/or the bedrock ledge function as barriers to upstream movement. However, it should also be noted that Mashburn Branch for a distance of 0.9 mi extending above and below Schley Farm Rd. flows through a pasture with no riparian buffer zone and frequent cattle access. Pools are few, poorly developed and heavily sedimented. In addition at this point it begins to diminish in size, and might not be attractive to migrating cyprinids even were it in a natural state.

Nickajack Creek

The lowermost two of several crossings on Nickajack Creek qualified for inclusion in the 2011 barriers field schedule. CUL-NIC-A, at River Rd. (SR 1672), was rated Indeterminate using the filters, while CUL-NIC-B, located 0.3 mi. upstream on Nickajack Rd. (SR 1674, was rated as Indeterminate for Filter B and impassable for Filter C.

CUL-NIC-A at low water is located less than 30 ft. above the Cullasaja River; during high flows this portion of the creek becomes part of the Cullasaja. Between that point and CUL-NIC-B, Nickajack Creek passes through mostly pasture land, dropping over a low bedrock ledge (not a barrier in its natural state) 50 ft. below Nickajack Rd. This reach has never been thoroughly surveyed, but the only species previously recorded were rainbow trout (*Oncorhynchus mykiss*), longnose dace (*Rhinichthys cataractae*) and mottled sculpin (*Cottus bairdii*). We have never surveyed Nickajack Creek above CUL-NIC-B.

The habitat available for sampling below CUL-NIC-A is very limited, consisting of a single 24 x 12 ft. pool, with a maximum depth of 1.9 ft. There we took a total of 6 native species, with 86.7% of the sample comprising 3 shiner species, including whitetail shiners. Almost all fish taken were juveniles or very small adults. The first pool above River Rd. produced similar results (80.4% shiners, with a total of 6 fish species), but only 2 small whitetail shiners, leading to a conclusion of at least limited passability, but with insufficient data to draw conclusions about the significance of Nickajack Creek for fall migrant cyprinids. Since no better pools were nearby, we elected to sample the pool below Nickajack Rd. at CULL-NIC-B as part of a determination both for that site and for CULL-NIC-A.

The pool below CULL-NIC-B is located directly above the aforementioned bedrock ledge, with a long, heavily sedimented tail below a round scour pool located directly below the culvert, and a maximum depth of 1.8 ft. The heavily sedimented tail area was almost devoid of fish, but in the upper portion of the pool we found a concentration of Tennessee shiners (60.8% of the sample) but only 2 small whitetail shiners.

However, we noted that a tree had fallen across the bedrock ledge, giving rise to a sediment and debris dam which formed a partial, and possibly total, barrier to upstream fish movement. Accordingly, we decided to sample the first pool below the ledge. There whitetail shiners of all sizes were found to form nearly half of the fish sample (48.6%). This led to the tentative interpretation that the rock ledge and debris jam were functioning as a barrier.

This conclusion was initially supported by results from above CULL-NIC-B. The upstream pool nearest the culvert contained only 1 whitetail shiner and no other shiners. However, since it was shallow (maximum depth 0.9 ft) and did not have a strong flow at the head, a second, smaller but deeper (maximum depth 1.9 ft.) pool, with a strong rapid at the head was sampled. There we found 38.9% whitetail shiners (all sizes) and a total of 55.6% shiners in the fish sample.

Both CUL-NIC-A and CUL-NIC-B are passable for migrating cyprinids, the impassable rating for CUL-NIC-B evaluated using the filters notwithstanding.

Walnut Creek

Two candidate barriers were considered simultaneously here. The lowermost putative barrier (CUL-WAL-A) located at Highlands Rd. (US 64) was rated Indeterminate by both filters, while CUL-WAL-B, located less than 50 ft. upstream and formed by the driveway for Pine Grove Baptist Church, was rated impassable by both filters. Thus the habitat between CUL-WAL-A and CUL-WAL-B, consisting of a single pool with a maximum depth of 3.1 ft., formed the upper half of one sample and the lower half of the other.

CUL-WAL-A is located less than 80 ft. above the Cullasaja River and there is no pool habitat between Highlands Road and the river. Thus it was not surprising to find a relatively low proportion of shiners (43.6%), with only one whitetail shiner. However, the results from the pool between the two barrier candidates clearly establish that CUL-WAL-A is not an effective barrier. Warpaint, Tennessee and whitetail shiners, in that order, were the most abundant fish in the pool, constituting 61.0% of the catch (18.2% whitetails of all sizes).

CUL-WAL-B forms a 28" drop from the lip of the culvert to the water surface below, so it is no surprise that fish sampling results supported the filter determinations in classifying it as impassable. In samples from 3 pools above CUL-WAL-B we found Walnut Creek to have only 6 fish species, as opposed to 13 in the pool downstream, with no shiners or other probable migratory fish. This correlates well with the results of 4 IBI fish samples carried out upstream at RM 0.6, where Walnut Creek crosses Walnut Creek Road between 1991 and 2008. In all cases we found 3-7 species, with no shiners or other likely migrants.

CUL-WAL-B is unequivocally a barrier to upstream fish movement. Although catch per unit effort in Walnut Creek between its mouth and CUL-WAL-B (52.1 fish per 300 sq. ft. of water surface) may reflect "piling up" of fish at the barrier, it is 2.5 times higher than the rate above CUL-WAL-B (21.1) suggesting unoccupied habitat.

Wallace Branch

Due to access problems, CAR-WAL-A was not evaluated using the filters. However, based on visual inspection it was considered to be Impassable for both filters. The single box culvert at U.S. 64 incorporates two barrier features – an inclined concrete apron at the upstream end which reduces water depth to a minimum over perhaps 20% of the culvert's length, and a 19 inch perch at the downstream end.

Access problems were resolved in time for the sampling season, and results strongly suggest that CAR-WAL-A is an effective barrier to upstream migration. Below the culvert, we took 53.9% shiners (50.0% natives, with a few yellowfin shiners), although this included only 7.8% whitetail shiners. Upstream no shiners were taken. This result could be considered not definitive due to inadequate sample size, related to low habitat quality.

Below CAR-WAL-A Wallace Branch is fully accessible by cattle, with badly eroding banks, heavily sedimented pools and a minimal riparian buffer zone. However, the quantitative fish catch was adequate for analytic purposes. Upstream, while the buffer zone is adequate, sedimentation is even worse. In a sample comprising 93 ft. of pool habitat, we took only 38 fish, for a catch rate of 13.6, less than a quarter the rate downstream (61.2), and the second lowest recorded for any above or below barrier segment in the study. Total species count was 5, compared to 13 species below the culvert.

Hayes Mill Creek

With a 12.6" perch at the downstream end, barrier candidate HAY-A (at Pete McCoy Rd. – SR 1728) was determined to be impassable for both filters. The fish sample results tend to confirm this conclusion. However, any analysis of Hayes Mill Creek above and below HAY-A must include a discussion of habitat quality.

Immediately below Pete McCoy Rd. habitat in Hayes Mill Creek consists of alternating bedrock runs, with characteristically low fish density and a variety of large and small, heavily sedimented pools. A 1995 IBI sample below HAY-A included one very large pool (maximum depth 2.5 ft.) dominated by creek chubs (*Semotilus atromaculatus*) and white suckers, with a smattering of "pond fish" (golden shiners, bluegills (*Lepomis macrochirus*) and largemouth bass). Migratory species were represented by only a few warpaint shiners and one golden redhorse, with no whitetail shiners in this summer sample. (It may be worth noting that only 1 yellowfin shiner was taken in 1995, vs. 17 plus one warpaint-yellowfin hybrid in 2011, thus helping to date the yellowfin shiner invasion.)

This pool was avoided in the downstream portion of the fall 2011 sample, in favor of a smaller pool (maximum depth 2.2 ft.) and a 43 ft. section of bedrock run, punctuated by pockets up to 0.8 ft. deep and terminating directly under the lower end of the culvert. While this sample did include a surprising number of bluegills (6) and single individuals of both largemouth and smallmouth bass, shiners accounted for 71.5% of the catch (59.0% if only native shiners are counted) and the whitetail shiner was the most numerous fish species, making up 25.0% of the sample. Over 2/3 of the whitetail shiners came from the pool, which comprised about a third of total sample length, but 11 whitetails, including some very large ones, were taken from pockets just below the culvert.

Hayes Mill Creek was the first site sampled on November 9, the sun had not yet reached the water, and we found shiners in the downstream pool to be concentrated in leaf litter and root masses. This leads us to wonder if, later in the day, some of these fish would have moved up and added to the observed small concentration of fish, principally whitetail shiners, immediately downstream of HAY-A.

The reach above HAY-A is better buffered than its downstream counterpart, appeared to have less deep sediment deposits in the pools, lacked reaches of unproductive bedrock substrate, and provided a normal alternation of riffle, run and pool habitats, with a maximum depth of 1.4 ft. However, in addition to lower fish diversity (7 vs. 13 species), and lack of shiners and other possible migrants, it had the lowest catch rate of any sample reach in the study (9.0 vs. 67.5 downstream), significantly lower than that of Wallace Branch above CAR-WAL-A, where physical habitat condition is clearly worse.

McDowell Branch

Barrier candidate MCD-A, located where McDowell Branch passes under Wide Horizon Drive (SR 1652), had the curious result of being rated Passable for Filter B and Impassable for Filter C. Biological analysis is similarly unclear. If we accept the relative abundance of the invasive exotic yellowfin shiner (23.3% of the sample below MCD-A and 11.5% above) as an indicator, then it is passable. This conclusion is supported by the results of IBI fish samples above Wide Horizon Drive in 1995, 2002 and 2005. In 1995 we recorded no yellowfins, but after 2002 it was abundant, indicating successful invasion through the culvert MCD-A during 1995-2002. The conclusion is further supported by the occasional presence of golden redhorse and the abundance of warpaint shiners in all 3 IBI samples (although only 3 individuals were taken in the Fall 2011 sample.) We will also note that, on a purely intuitive basis, MCD-A would not appear to be impassable. We will tentatively classify MCD-A as Passable, based on biological criteria, while noting that habitat may play a role in the limited presence of whitetail shiners (2 adults) and golden redhorse (1 juvenile) below Wide Horizon Drive in 2011.

Fulcher Branch

Fulcher Branch, the smallest stream included in this study, with a total drainage area of just over 1 mi^2, also presents one of the most curious conditions, both in terms of history and 2011 results. The barrier candidate FUL-A was rated Impassable for both filters, and the visual evidence supports this claim. The culvert where Fulcher Branch passes under Clarks Chapel Rd. (SR 1646) is not only quite steeply inclined, but discharges on top of a natural barrier formed by a series of cascades; the total drop between the lower end of the culvert and the surface of the pool below the cascades is 39 inches. Yet we have to classify FUL-A as a “filter” or “partial barrier”.

Except for a small pool directly below the cascade, Fulcher Branch below FUL-A is totally channelized through mowed yards, with no significant vegetative buffer beyond grass. Substrate condition is relatively good, however, with a substantial amount of large gravel and small cobble, and limited habitat is provided by long, flat pools, with a maximum depth of 1.1 ft. In this reach, which we had never sampled before, we found a surprising concentration of (in order of abundance) yellowfin, Tennessee, warpaint and whitetail shiners, mostly small adults. Together these shiners comprised 72.8% of the total fish sample. In the wider, better defined but shallow (maximum depth 1.0 ft.) pool below the cascade, however, while total shiners were fewer (52.5%) the whitetail shiner was the second species in abundance (after the central stoneroller). Here whitetails comprised 22.5% of the total sample, and there was a full representation of sizes.

Upon completion of the pool sample we quickly electrofished one small pocket in the bedrock of the cascade. This pocket, measuring about 2 x 3 ft. contained one adult whitetail shiner. To reach this point at normal water levels, this individual would have had to make a vertical leap of about 2.5 ft. This suggested the possibility of whitetail shiners surmounting the FUL-A complex, and this was confirmed by the capture of 2 medium size adult whitetails not far above Clarks Chapel Rd.

We also found 9 yellowfin shiners above FUL-A, raising the question of how these nominally weak swimmers, which generally prefer habitat with moderate velocity, transcended the barrier. This question becomes even more interesting when we consider the relative abundance (5.8% of total fish) of yellowfin shiners above FUL-A in a 1995 IBI sample. This is in contrast to the situation in more easily accessible sites in Hayes Mill, McDowell, Hickory Knoll and Mulberry Creeks, where yellowfin shiners were very rare or absent in 2005 samples, but later became abundant. At that same time (1995), smoky dace were the single most abundant species in Fulcher Branch above Clarks Chapel Rd. (35.0% of the sample), but in the 2011 fall sample we failed to capture a single smoky dace.

If we look at Fulcher Branch and FUL-A in terms of “incentive”, the reach above the barrier appears to present near-ideal habitat for yellowfin shiners, good habitat for smoky dace, and mediocre habitat for whitetail shiners. It is tempting to say that yellowfin shiners have successfully invaded and displaced smoky dace, but such a drastic result has not occurred in the other nearby streams just mentioned.

In terms of relative passability, FUL-A would appear to represent the most difficult barrier in this study, excluding those which incorporate a significant vertical drop over a uniform, artificial lip. Yet FUL-A has been successfully passed by the weakest swimmer among our indicator species (yellowfin shiner) and also by a strong swimmer/leaper (whitetail shiner) which would appear to have little to gain by colonizing upper Fulcher Branch.

<u>North Fork of Skeenah Creek</u>

Barrier candidate SKE-NOR-AA, rated Indeterminate for both filters, is a single pipe culvert located on a private farm road. It was discovered only after all barrier candidates had supposedly been defined, through conversation with the owner of the clearly passable SKE-NOR-A, located on Misty Meadow Lane, the principal access road to the same property. SKE-NOR-A is located near the lower property boundary; much of the stream bank from there upstream to SKE-NOR-AA and beyond, at least to the upstream property line, is poorly buffered and unstable, with raw banks and severe undercuts.

The culvert at SKE-NOR-AA is clearly undersized, and forms an enormous scour pool (35 x 25 ft. with a maximum depth of 3.5 ft.) which is totally out of character with the rest of the stream. Like most of North Fork Skeenah Creek on the property it has unstable, eroding banks. The margins are heavily sedimented. What appears to be a gray water drain of undetermined origin enters near the upper end, forming a separate small pool.

The pool below SKE-NOR-AA was visibly heavily populated with fish. While the catch rate below the culvert (28.8) was higher than that above (25.8), these numbers do not reflect the actual concentration of fish. The combination of a large area and volume of water, much of it deep, the absence of a clear current pattern except at the very head of the pool, and the turbidity occasioned by our activity would have necessitated multiple passes with the electrofisher in order to obtain anything approaching a complete sample. This would have likely resulted in an unacceptable rate of mortality, so we elected to sample just enough to determine the status of target species.

The results include 11 bluegills (mostly small adults), one large brown bullhead (*Ameiurus nebulosus*) (the only representative of this exotic species taken in the current study) and a large juvenile largemouth bass. Although bluegill and largemouth bass are native to the watershed, all of these fish very likely represent the understandable temptation to informally stock a pool of this dimension.

Even with the inclusion of these “pond fish”, the attraction of the pool for whitetail shiners was clear. Whitetails were the most abundant fish in the pool, constituting 36.9% of the catch. The total proportion of shiners was 72.6%, and native shiners (excluding yellowfin) accounted for 59.5%.

Habitat for shiners above SKE-NOR-AA to the upstream boundary of the property was mediocre. Pools were ill-defined, short and heavily sedimented, with a maximum depth of 1.8 ft. The only whitetail shiners taken (5 individuals, forming 5.6% of the total sample above SKE-NOR-AA) were found in a small undercut pocket located immediately above the head of the culvert. (Netting was very difficult here, and it is not unlikely that more whitetails were missed.)

Yellowfin shiner was the most abundant fish above the culvert, accounting for 38.2% of the sample there. The only other migratory fish present over the length of a 115 ft. section of stream sampled were 3 young-of-the-year and one adult warpaint shiner. We did not have access permission to facilitate sampling upstream of the property on which SKE-NOR-A and SKE-NOR-AA are located but, based on past visual observation at least some stretches of the North Fork of Skeenah Creek above this point are in better condition, and might offer suitable habitat for migratory cyprinids.

We have tentatively rated SKE-NOR-AA as a “partial barrier” based on biological sampling, but it might in fact be fully passable and the scarcity of whitetail shiners and other migratory cyprinids above it may simply reflect the absence of attractive habitat.

Bates Branch

Bates Branch is easily the most atypical of the streams included in this study, and the same may be said of its barrier candidate, BAT-A, formed where the stream passes under US Highway 441. This double box culvert (incorporating two bends which greatly complicated the survey process) was rated Impassable for both filters, but both this fall’s work and previous IBI monitoring (1995 and 2003) suggest that it is completely Passable. We suggest that the discrepancy may be due to the unusual conformation of this culvert, and/or its great length (113 ft.).

The physical condition of Bates Branch above and below BAT-A also confounds any attempts at biological above-and-below comparison. Below BAT-A, Bates Branch has been channelized over most or all of its short length to the Little Tennessee River. Such pools as exist are mainly heavily sedimented pockets formed under tree roots along either bank. The soft substrate and lack of strong flow into the heads of these pools render them unlikely candidates for concentrations of migratory cyprinids, and we would likely have found them to be largely populated by temporary “visitors” from the river.

We therefore concentrated our sampling downstream of BAT-A in 101 ft. of linear pool/run habitat, with a maximum depth of 1.9 ft., connected by very short rubble riffles, located immediately downstream of the culvert. Despite marginal habitat quality, we found moderate numbers of all 3 native shiners (23.9% of the sample). Yellowfin shiner was the most numerous species here; if it is included the proportion of shiners in the sample climbs to 50.4%.

Almost the entire length of Bates Branch from the upstream end of BAT-A to the mouth of Hoglot Branch, a tributary above which Bates Branch becomes substantially smaller, is in the form of a uniformly deep linear pool (maximum depth 4.3 ft.) with grassy undercuts along one side and shallow water on the other. The great majority of the substrate is composed of loose silt. A single small pool at the upper end provides more typical stream habitat, presumably more suitable for most cyprinid species.

Our fish catch, spread over 146 ft. of this highly atypical habitat, was dominated by mostly very small juvenile bluegills (63.1% of the total sample). However, we did encounter 5 large whitetail shiners and 4 adult warpaint shiners above BAT-A. Further proof of passability is provided by the yellowfin shiner, the second most abundant species above the culvert (21.6% of the sample), and present above and below BAT-A in both previous IBI samples.

Hickory Knoll Creek

Of four crossings on Hickory Knoll Creek selected for initial survey, two were selected for biological sampling. HIC-A, at Hickory Knoll Rd. (SR 1653), 0.4 mi. above Hickory Knoll Creek's mouth at the Little Tennessee River, was rated Passable for Filter B and Indeterminate for Filter C. HIC-D, located 2.3 mi. further upstream on Gorda Lane, was rated Impassable for both filters.

Prior evidence for the passability of HIC-A is provided by IBI fish samples taken in 1995, 2001 and 2007. The 1995 sample included only 1 yellowfin shiner, out of 550 total fish. However in both 2001 and 2007 yellowfin shiner was the second most abundant species (8.2 and 15.9% of total samples) after the extremely dominant mottled sculpin, demonstrating that this exotic species successfully invaded from the Little Tennessee River, through HIC-A, between 1995 and 2001.

Our fall 2011 sample produced modest numbers of yellowfin and whitetail shiners (6.5% in both cases), but greater proportions of warpaint and Tennessee shiners (26.9 and 25.0%, respectively), along with one juvenile black redhorse. These observations lead to a determination of Passable, but numbers of whitetail shiners were below expectations.

We did not have access to Hickory Knoll Creek directly below Hickory Knoll Rd., so the downstream half of our paired sample related to HIC-A was accessed by entering at the mouth of the creek. There the substrate was predominantly sandy and pools were more poorly defined and less stable than above HIC-A. Yellowfin shiner was the single most abundant species, constituting 27.9% of the sample. Representation of native shiners (48.5%) was lower than above HIC-A (58.3%) and all 3 species were represented primarily by small individuals.

A possible explanation for the relatively low abundance of whitetail shiners in particular, and the dominance of small shiners at our downstream sample site was provided by the discovery of a huge beaver dam, located about 180 ft. above the mouth. This dam, about 5 ft. high, impounds a long reach upstream. The combination of dam and pond certainly presents some degree of difficulty for upstream migrating fish, and may require leaping or other behavior which favors larger individuals, thus explaining the predominance of small shiners downstream.

We found no shiners or other potential migrants above or below HIC-D. We carried out only limited sampling (227 sq. ft.) above HIC-D, since we had failed to identify any fall migrants downstream. However, there are clearly differences between the two samples related to habitat quality. Below Gorda Lane, the habitat is dominated by a large scour pool (maximum depth 2.9 ft.). Here and in the immediate downstream reach, comprised of rubble riffles and smaller pools, the stream is fairly well buffered and completely shaded, and appears to be in its natural channel. The most abundant species in pool habitat was the smoky dace (38.7% of the sample), represented principally by large adults. Other common species were rainbow trout (adults up to 8" TL), creek chub and, in the shallower areas, mottled sculpin.

Above HIC-D, Hickory Knoll is historically channelized and flows through a pasture with virtually no riparian vegetation other than grass. Pools are poorly developed, with a maximum depth of 1.0 ft. Most of the same species were present, but as small individuals in small numbers. The only species which was well represented, with a full range of sizes, was the mottled sculpin. Catch rate above HIC-D was 20.7 vs. 39.1 downstream.

In this situation, biological sampling is an insufficient tool for determining the passability of the culvert at HIC-D. The more interesting question is whether the absence below HIC-D of 10 species (including all 4 shiners) found above HIC-A is due to the presence of an undetected barrier somewhere along the 2.3 mi. between HIC-A and HIC-D.

To begin to answer this question, we visually reviewed any visible crossing between HIC-D and HIC-B;, however, all identified crossings were clearly passable. HIC-B, located at Slep Orchard Rd., 0.3 mi. upstream of HIC-A was rated passable for both barriers, but does have a slight perch at low water. In addition, any fish emerging from the upper end of this pipe culvert is immediately confronted with a strong riffle. This raised the possibility that HIC-B functions as at least a partial barrier. To test this possibility, we sampled a single pool with strong flow at the head, located 150 ft. upstream of HIC-B. Since the intent was merely to determine the presence of migratory cyprinids, this habitat was not surveyed exhaustively. Even so, it had a high catch rate (93.3) and contained at least 10 of 14 total species identified above HIC-A. More significant was the high proportion of shiners (54.1%) and native shiners (50.0%), with strong representation by whitetail shiners (16.3%) of all sizes. This clearly confirms the evaluation of HIC-B as Passable.

Another aspect of the sample above HIC-B merits mention. It is generally supposed that the watershed endemic smoky dace, a species which seems to be in decline, benefits from lack of competition by shiners. This supposition is at least partially supported by our data. We have on occasion observed (including in Mulberry Creek in this study) schools of smoky dace occupying the middle of pools in the absence of shiners, whereas in more diverse streams they tend to be limited to shoreline habitat, with consequent lower abundance. However, there are exceptions and Hickory Knoll Creek above Slep Orchard Rd appears to be one. At this site, where it shared habitat with whitetail, warpaint, Tennessee and yellowfin shiners, smoky dace was the single most abundant species, comprising 27.6% of the total sample.

We incline toward the belief that there are no undetected barriers between HIC-B and HIC-D, and no putative barriers were detected while driving along Hickory Knoll Rd. parallel to the creek. However, a complete investigation would have required multiple access permissions. We suspect that the absence of fall migrants below HIC-D reflects a natural habitat transition (altitude, gradient, temperature?) over 2.3 mi. of stream.

Mulberry Creek

Based on two 1995 IBI monitoring samples – one just above barrier candidate MUL-A at US Highway 441 and one at RM 0.9 (Carpenter Rd.), Mulberry Creek is probably the healthiest of the 9 streams included in this study (No IBI data are available for Nickajack Creek, Wallace Branch or the North Fork of Skeenah Creek, but all are visibly degraded). Based on application of the filters, MUL-A was rated as Indeterminate for Filter B and Impassable for Filter C. Application of biological criteria led to a conclusion of differential passability ("filter").

The yellowfin shiner provides evidence suggesting passability. The 1995 IBI sample above MUL-A included only a single yellowfin shiner, 3 warpaint shiners and 1 Tennessee shiner among 541 fish, representing 16 species, and no yellowfins were taken at RM 0.9. While the 2011 fall sample yielded no Tennessee shiners and only 5 medium size warpaint shiners, yellowfin shiners were the third most abundant species (after creek chub and mottled sculpin) comprising 17.4% of the total sample. This clearly suggests invasion of Mulberry Creek above US 441 by yellowfin shiners between 1995 and 2011.

However, the matter is complicated by consideration of the fall 2011 data from downstream of MUL-A. Although the 0.1 mi. of stream between the highway and the Little Tennessee River is heavily impacted by beaver activity (2 low dams in place on the day of sampling), we found both whitetail and warpaint shiners of all sizes to be abundant, with each species comprising 22.2% of the sample. There were also a few small Tennessee shiners. The distribution pattern strongly suggests the "pile-up" phenomenon often observed at the foot of total or partial barriers. (CUL-WAL-B and FUL-A provide particularly clear examples in this study.)

Discussion

Prioritization

Sites are here prioritized only in the context of the present study area. Tributary streams with watershed areas of greater than 2 mi^2 below Porters Bend Dam (Lake Emory), for nearly all of which the spotfin chub has been documented in fall sampling, rate a higher priority on that basis alone. Based on our findings we assigned a medium or low priority to each site. Our evaluation admittedly has a significant aspect of subjectivity, and should be subject to revision by all of the participants in the larger study, and others. Given our method of surveying for migratory fishes, and the only species with a clearly defined seasonal migration being a cyprinid, our conclusions on passability are only applicable to the Filter B fishes. We were unable to biologically assess passability for the weakest swimming fish (Filter C), without employing a more labor intensive and cost prohibitive sampling design (i.e. mark-recapture). Factors taken into consideration in assigning priority included:

Relative passability: We would tend to assign a high priority to a barrier judged to be totally impassable by small cyprinids. A site determined to be completely passable is automatically rated as zero priority. This would seem to lead to black-and-white comparisons. However, our experience inclines us to recognize differential permeability, leading to a generous grey area between putative barriers which turned out to be totally passable and totally impassable obstacles.

Proximity to the mainstem: Sites closer to the mainstems of the Little Tennessee River, Cullasaja River and Cartoogechaye Creek should rate a higher priority than similar sites further upstream.

Watershed area and stream length above the barrier: The more potential habitat that lies above a barrier, the higher the priority given to its removal.

Proximity to other barriers: Sites located not far downstream from an impassable natural barrier, such as a waterfall, are considered to merit lower priority than those distant from such barriers. In the case of adjacent anthropogenic barriers, all aspects of both barriers, including the combined cost of remediation, must be taken into account in evaluating either barrier. Normally if it is not deemed feasible to remove both barriers, both would receive a low priority.

Location in the watershed: Above a certain point in each tributary watershed a combination of factors (stream size, temperature, gradient, altitude) combine to limit, and eventually eliminate, migratory and river-dependent fish. It can be argued that even in streams dominated by non-migratory headwater species fragmentation by anthropogenic barriers can negatively impact long term population viability. Our methodology is not able to detect this type of barrier effect. It could also be pointed out under present conditions, some anthropogenic barriers may serve a positive function in protecting sensitive headwater species such as brook trout from invasion by species from the lower watershed. For these reasons we considered absence of migratory fish below a barrier site as a factor lowering removal priority.

Habitat quality above the barrier: If habitat for a particular species is missing or marginal above a barrier, removal of that barrier will likely have little or no effect on the welfare of that species. It is of course possible to envision projects which combine barrier removal with habitat restoration over a larger area (as is presently occurring in Watauga Creek below Lake Emory). However for purposes of this study we have considered the probable effects of barrier removal in isolation. In our opinion consistently poor habitat above a barrier would preclude assigning a high priority.

Habitat quality below the barrier: Barring lethal conditions, fish will pass through unsuitable or marginal habitat to reach an upstream destination. We have no criteria for determining how long the degraded habitat reach has to be, or how severe the degradation before it functions as a barrier or “filter” (See discussion below) for upstream migrants. In general we took downstream habitat quality to be a minor factor in prioritization.

Cost: In very general terms we tended to assign a higher priority to those barriers which appeared to be susceptible to relatively low cost replacement and vice versa. This factor will need to be revisited in detail for those sites where replacement is seriously considered.

Sites not visited by the biomonitoring team:

With one exception (SKE-NOR-C, see below) ten sites which were rated impassable or indeterminate using the filters, but which were not sampled in the study were automatically assigned a low priority. Following are brief descriptions of these streams and specific sites and our rationale for not pursuing them. Any of them could be reconsidered for barrier removal based on considerations not related to migratory cyprinid movement.

Ellijay Creek watershed: Sites CULL-ELL-LAU-A, B and C, located on Laurel Branch, tributary to Ellijay Creek, were all located within 0.2 mi. of each other on separate private properties in the upper reaches of the watershed. Laurel Branch here has a high gradient and it was judged unlikely that we would find fish other than a few headwater species. Given the costs and complications implicit in negotiating and executing 3 separate barrier removals on 3 separate properties, we elected not to invest sampling time on Laurel Branch.

Site CUL-ELL-WiL-A is located on Wildcat Branch, also tributary to Ellijay Creek . It is located just 80m downstream of a natural waterfall barrier in a high gradient, high altitude (2686 ft) reach. A 1993 summer survey of upper Wildcat Creek showed rainbow trout to be the only fish species present.

Poplar Cove Creek watershed: Sites CAR-POP-A & BC, located on Poplar Cove Creek, tributary to Cartoogechaye Creek, are located on separate private properties in the high gradient upper reaches of the stream. A 1993 summer survey between these two sites yielded only 3 fish species – rainbow trout, brown trout (*Salmo trutta*) and mottled sculpin.

Skeenah Creek watershed: We were unable to obtain access permission to sample SKE-NOR-C. Based on the results of the filter team survey, including a 12 inch vertical drop, it is likely that we would have found SKE-NOR-C impassable. See further discussion below under SKE-NOR-AA. We did not sample either of the 2 crossings in South Fork Skeenah Creek rated as "Impassable" by the physical survey. Those sites had a greater distance to the mainstem (3.0 and 3.2 miles) than any of the other sites we re-visited, and were longitudinally closer to the headwaters than to the mouth of Skeenah Creek. The reach from the crossings to the confluence with North Fork Skeenah Creek is approximately 1 mi. with roughly 0.6 mi. of channelized and/or unshaded stream. Therefore, a biological survey was omitted for South Fork Skeenah Creek.

Coweeta Creek watershed: The upper watershed of Coweeta Creek on the USFS Coweeta Hydrologic Laboratory property, including Site COW-SHO-B, on Shope Fork, which, together with Ball Creek, forms Coweeta Creek, constitutes a special case. COW-SHO-B, consisting of two different types of culvert, probably installed at different times, presents an extremely complex situation. For this reason it was selected as a training site in the filter assessment component of the project. It is located upstream of a long-established flow measurement weir on Shope Fork. This weir, and its counterpart on Ball Creek, likely constitute impassable barriers (not susceptible to analysis using the filter formulae). There is close to zero likelihood of modification of the weirs to improve fish passage. Nor, considering the tremendous scientific value of maintaining the weirs, would there be any justification. In addition, Shope Fork at COW-SHO-B is a high gradient stream from which, according to records kept at Coweeta Lab, only headwater fish species have ever been recorded. Thus in our opinion COW-SHO-B merits a very low priority for removal.

Sites sampled to determine passability by fish:

We did not consider that the probable biological benefit from potentially costly work to replace any of the 15 barrier candidates where we carried out fish samples justified a high priority. If a sensitive migratory species such as spotfin chub were present at any of the medium priority sites we would probably have assigned a high priority. Overall we identified 12 low priority and 3 medium priority barriers. They are discussed below in rough order from the lowest to highest priority. For the sake of convenience and clarity the discussion is organized on the basis of individual tributary systems (total of 12) so that in one case (Walnut Creek) a low and medium priority barrier are discussed together.

LOW PRIORITY

Nickajack Creek: We found both of the barrier candidates on Nickajack Creek rated as indeterminate by the filter team (CUL-NIC-A & B) to be completely passable by cyprinids (Filter B).

McDowell Branch: MCD-A was confirmed to be completely passable for all Filter B fishes. This fact, combined with generally poor habitat for most of these species both downstream and upstream of Wide Horizon Drive (SR 1652) render alterations to MCD-A a poor investment.

Mashburn Branch: While we identified a possible impassable barrier upstream of the identified barrier candidate CUL-MAS-A, which proved to be passable, the small size of the stream here (watershed area ca. 1.1 mi^2), the existence of an apparent natural barrier just above the presumptive culvert barrier, and the very poor habitat quality upstream suggest that while replacing the culvert on Schley Farm Road might yield other environmental benefits, the effect on fish movement would be virtually nil.

Hayes Mill Creek: The poor habitat quality above HAY-A, verified by the surprising scarcity of fish render modifications to HAY-A a poor investment at this time. It should also be noted that Hayes Mill Creek divides not far above HAY-A, so that even with adequate habitat restoration, reduced stream size might result in minimal benefits to migratory fish.

Wallace Branch: Two factors suggest assigning a low priority to CUL-WAL-A, a box culvert under US 64. It appears to us that replacing or modifying a culvert under a 4-lane highway which appears to present physical difficulties to upstream migrant fish at both ends would be extremely costly. Even so, it might be considered were it not for the extremely poor condition of the stream both above and below the highway, a condition which (based on superficial examination) obtains over most of its length between the National Forest boundary at the end of Wallace Branch Rd. (SR 1314) and its mouth at Cartoogechaye Creek. Extensive work on CUL-WAL-A would appear to us to be justifiable only in the context of a major watershed restoration effort spanning nearly 3 miles of stream.

Bates Branch: The present study and previous sampling in Bates Branch above US 441 suggest that BAT-A is completely passable by Filter B fishes. This culvert is very long (113 ft) and lack of habitat structure within it could be reducing the number of whitetail shiners and others which ascend it, but the very poor quality of habitat from the Little Tennessee River to BAT-A (0.08 mi) and for a considerable distance above it reduce the attractiveness of concepts such as placement of baffles in the culvert. Caveat: There may be somewhat better habitat in Bates Branch above the mouth of Hoglot Branch.

Fulcher Branch: FUL-A, at Clarks Chapel Rd. (SR 1646) can only be described as an anomalous situation. While further study of Fulcher Branch could be very productive in terms of enhancing our knowledge of fish migration/barrier issues, given the small size of the stream and the mediocre habitat available above FUL-A, any return on investment in improvement would likely be marginal.

Hickory Knoll Creek: Passibility for Filter B fishes was confirmed for HIC-A, at Hickory Knoll Rd. (SR 1653). Due to the characteristics of the fish assemblage we are not able to comment on HIC-D, at Gorda Lane, rated impassable by the filter team. There is a considerable length Hickory Knoll Creek above HIC-D, with a 2.5 sq. mi. watershed so that modification of HIC-D based on fragmentation concerns, might be justifiable. It could also be worthwhile to walk the 2.1 mi. of Hickory Knoll Creek between HIC-A and HIC-D to ascertain that there are not other barriers contributing to the low fish diversity below HIC-D. The beaver dam situation near the mouth also merits investigation; while our results clearly demonstrate that the existing dam is porous to fish, it is difficult to imagine that it does not to some degree reduce transitability by migrating fish.

MEDIUM PRIORITY

Walnut Creek: While we found CUL-WAL-A, at US 64 to be completely passable for cyprinids, CUL-WAL-B, located just 50 ft. upstream is the most formidable barrier we have found. Removing this barrier would make available 0.5 mi. of good quality habitat (up to at least the beginning of a high gradient reach above Walnut Creek Rd.). Apart from the presumable high cost of modifying CUL-WAL-B, there may be a fishery argument against opening up lower Walnut Creek. We were surprised at the abundance and size of both rainbow and brown trout; the two species together comprised 20.0% of the sample, with some individuals over 12 inches TL. Allowing access to shiners and other native species, including aggressive pioneer species such as river chub, would likely lead to competition for resources and reduced abundance and size of trout.

Skeenah Creek: It appears that such passability problems as SKE-NOR-AA has could be at least temporarily remedied by removing a log and associated debris which have accumulated at the top of the culvert. However, more permanent restoration would likely require replacement of the culvert, a step which would diminish the size of the downstream scour pool. Ideally, this would be accompanied by riparian restoration along the entire length of the stream on the property where SKE-NOR-AA is located.

This could be one of the more cost-effective opportunities resulting from this project. Elimination of the barrier at SKE-NOR-AA would open up at least 1.1 miles of stream, up to SKE-NOR-C, which is rated impassable for both filters, largely due to a 12 inch vertical drop. We were unable to obtain access permission to sample at SKE-NOR-C, but if it were ultimately possible to modify this barrier, a still greater length of the relatively low gradient North Fork of Skeenah Creek could be connected. A necessary precondition to removal of either of the barriers on this stream would be at least a detailed visual survey of the 1.1 miles of stream between SKE-NOR-AA and SKE-NOR-C.

Mulberry Creek: The same question occurs as on Fulcher Branch. How can a barrier be surmountable by a small, relatively weak swimming cyprinid with a preference for moderate current (yellowfin shiner) and not by a larger, more vigorous species which is attracted to high flows (whitetail shiner)? In this case, the possible answer based on lack of incentive due to poor habitat above the barrier does not seem to apply.

At first glance, unresolved mysteries notwithstanding, MUL-A would seem to be a good candidate for restoration. The barrier structure is atypical, with a sill that has a perch of about 12 inches at the upstream end of the culvert (rather than downstream, as normal) as the main contributing factor. It would seem to be a simple matter to notch this barrier to facilitate upstream movement by fish. This would open up nearly a mile of good quality, well buffered stream.

One limiting factor might be beaver activity. At varying times in the past year we have observed beaver dams at 6 different locations on Mulberry Creek between the mouth and the upstream end of the sample reach above MUL-A. However, a more serious consideration has to do with conflicting conservation objectives. High species diversity notwithstanding, Mulberry Creek above US 441 supports one of the strongest populations of smoky dace in the watershed (11.3% of the 1995 IBI sample and 9.1% of the fall 2011 sample, even with competition from yellowfin shiners). Creating access for whitetail, warpaint and Tennessee shiners might create additional competition to the detriment of this endemic species. We will offer no opinion on this decision in this report.

Conclusions

This report implies the necessity to make decisions, based largely on cost-benefit considerations, about whether or not to attempt to achieve mitigation by modifying or removing barriers to fish movement, in at least one case (North Fork Skeenah Creek) in the context of a larger watershed restoration project. Beyond immediate decisions, it has provided us with insights into connectivity/fragmentation issues at a level well beyond consideration of individual barriers. Here we offer these insights in the hope that they can help guide the work of all concerned with stream ecosystem health in the Little Tennessee watershed and surrounding areas.

The concept of “barriers” to fish movement, which has guided this and earlier work is not as simple as one would like it to be. To be sure, there is such a thing as an absolute barrier to upstream fish movement – in this study CUL-WAL-B and CAR-WAL-A (Walnut Creek and Wallace Branch) provide examples. But there appear to be many intermediate situations, involving what can perhaps best be described as “relative” barriers, or “filters” (we hesitate to introduce the term “filter” into a discussion where it already has another meaning).

The goal of barrier removal, and the concept which informs this study, is to reduce anthropogenic fragmentation of streams and reestablish biological connectivity along altitudinal stream gradients. Identification and elimination of absolute barriers can be a powerful step toward this goal, and in some cases may be sufficient. However, as most of the results of this study suggest, it may often not be the most important thing we can do to restore connectivity. For example, on Wallace Branch, a costly barrier elimination effort might totally succeed on its own terms, yet have no positive effect on the health of the stream ecosystem.

One of the smallest, and arguably least important, streams included in this study, Fulcher Branch, can serve as an example to illustrate the need for a new approach to barrier assessment. At a glance, FUL-A, consisting of two inclined pipes perched atop a small natural cascade located just below where Fulcher Branch crosses under Clarks Chapel Rd., would seem to represent a formidable barrier, and it was so identified by the filter team. And yet above Clarks Chapel Rd. we found a strong population of yellowfin shiner, an exotic invasive species which sometime around 1990 entered Fulcher Branch from the Little Tennessee River , plus a very few whitetail shiners.

Both of these cyprinid species had to surmount a total perch of 39 inches and then ascend through fast water in an inclined pipe in order to arrive above Clarks Chapel Rd. This is presumably accomplished step wise, taking advantage of resting opportunities provided by tiny patches of still water within the cascade. Doing so must require an extreme investment of energy, with potential consequences in terms of survivorship, and the possibility of failing enroute. We can only speculate as to whether the number of migrating whitetail shiners above the cascade would be greater if to the barrier presented by the cascade the added obstacle of the culvert pipe had not been added. The dense concentration of whitetail shiners below the cascade and their low numbers above suggest that the combined effect of cascade plus culvert is to filter whitetail shiners.

The barrier FUL-A is not the only factor “filtering” whitetail shiners and other fish in Fulcher Branch. For 0.2 mi. between FUL-A and the Little Tennessee River, Fulcher Branch is strictly channelized as a ditch draining a large lawn, with no shade, no woody riparian vegetation and greatly reduced feeding and resting habitat. Whitetail shiners ascending Fulcher Branch from the river now are clearly exposed to stresses they did not have to sustain when natural conditions obtained on the lower reaches of the stream. It is logical to assume that this affects the numbers of this and other migratory species which make it upstream to confront Barrier FUL-A.

Above Clarks Chapel Rd., Fulcher Branch is heavily sedimented as the consequence of multiple land use decisions in a densely populated area, resulting in marginal habitat for whitetail shiners. There is no way of assessing the relative importance of this factor in determining the abundance of whitetail shiners above barrier FUL-A as compared to the two downstream barrier/filters just discussed.
At present, whitetail shiners probably extend as far upstream in Fulcher Branch as they ever did. If we treat this observation superficially, we may conclude that Fulcher Branch has maintained full connectivity. Yet if the total number of this species is being filtered by the results of human activity, what we have is compromised connectivity.

The question being raised is whether it is possible to arrive at a new definition of “barrier” which includes both absolute barriers, such as dams lacking any sort of fish passage facility, and relative barriers, or filters, which could include factors which:

- Render reaches of stream unattractive to migratory species. For some species this might be reaches which totally lack riparian shade.
- Reduce the survival rate of migratory fish (for example through exposure to predation or elimination of food resources)
- Incur increased energy costs (as for example the culvert on Fulcher Branch).
- Reduce available habitat in headwater areas for species which successfully pass through downstream filters.

If a rapid visual barrier analysis could be carried simultaneously with other assessment procedures which together would lead to a catalog of stresses along the length of a stream, with an estimate of the relative barrier effect of each stress (channelization, damage to riparian zones, different types of pollution, etc.) it could multiply the number of stream reaches which can be evaluated, while reducing the need for costly and time consuming activities. Technical procedures such as the two used in this study (the USFS filters and fish sampling) could still be applied in selected cases. Such procedures would facilitate the prioritization of mitigation and restoration activities. In this process, biological monitoring could be used, as in the present study, to determine the success of migratory movements, but also to assess before-and-after effects on more sedentary species and assemblages which presumably also benefit from enhanced connectivity.

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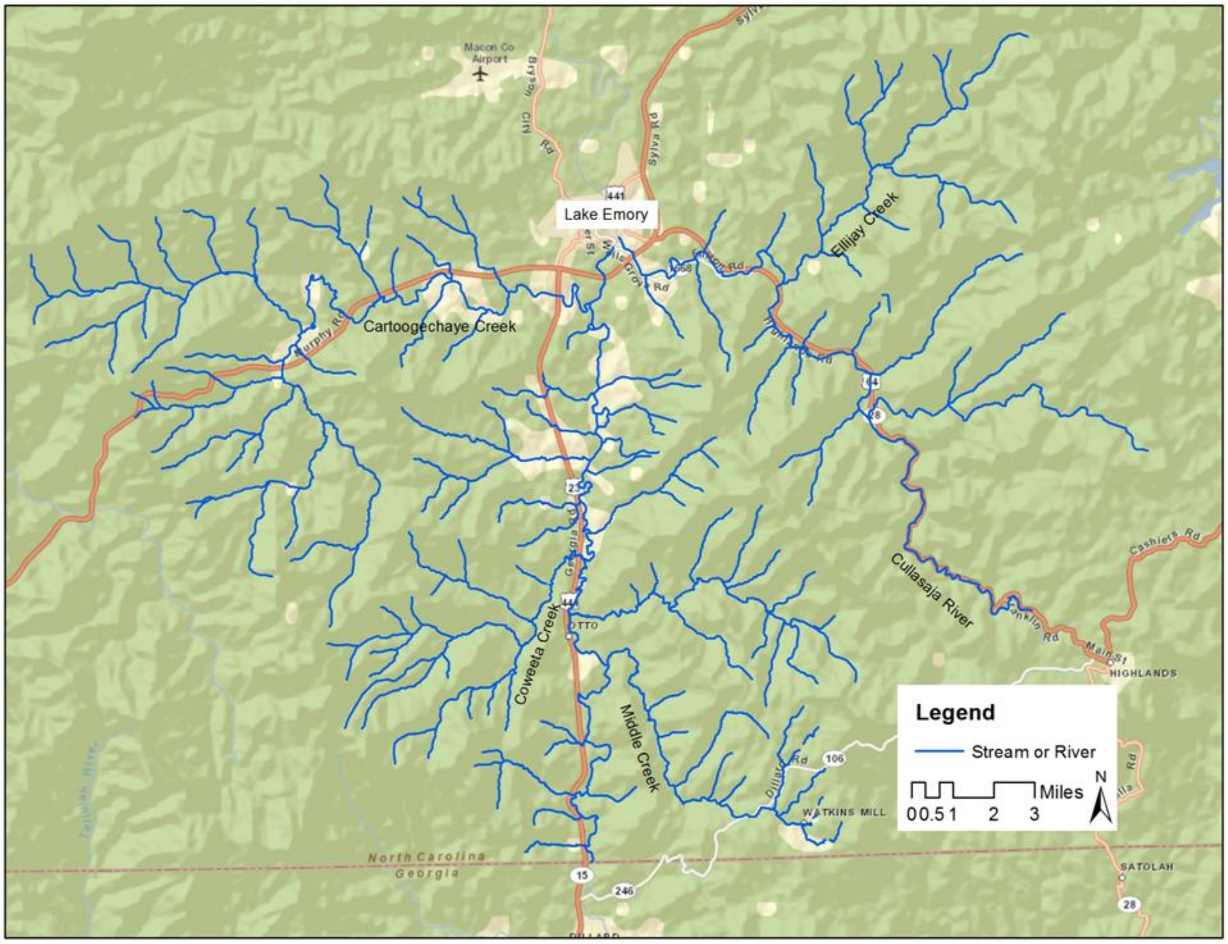
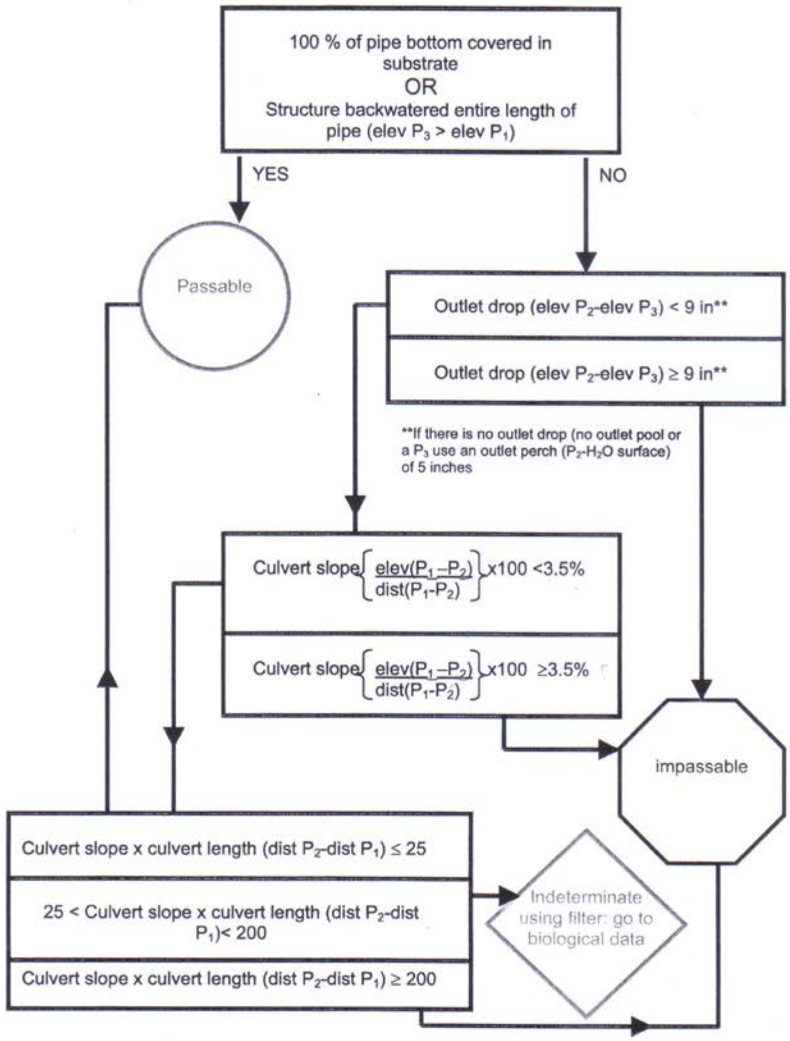


Figure 1. Study area.

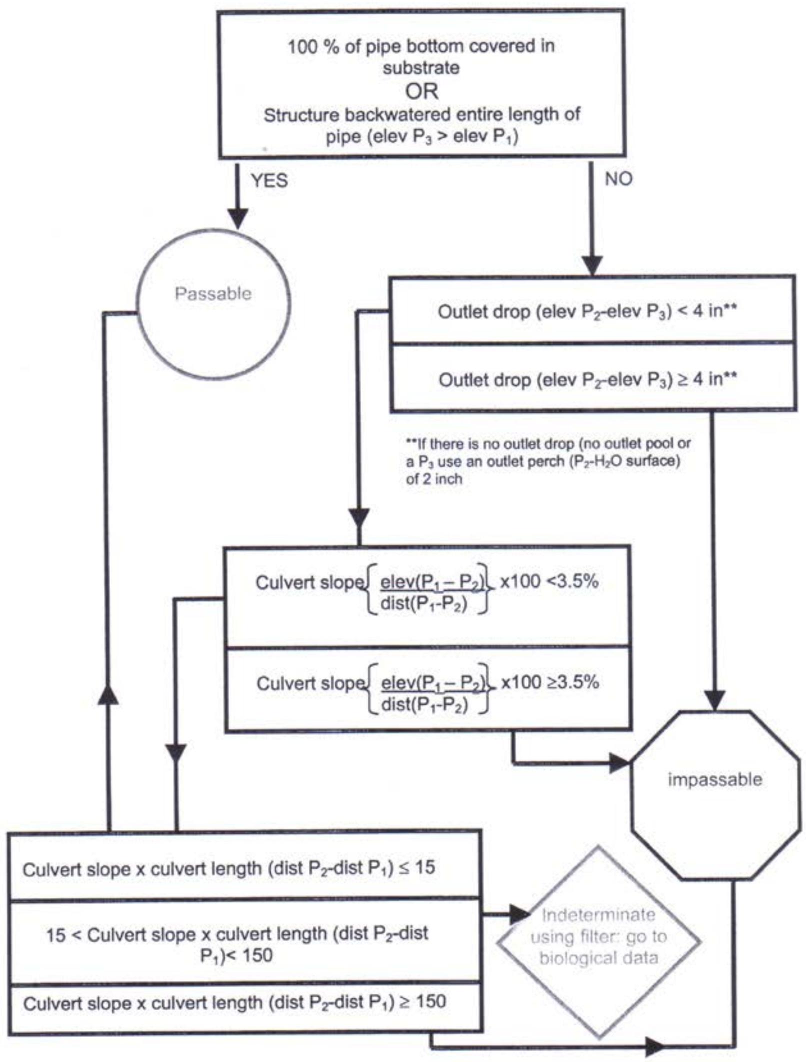
Coarse Filter B Cyprinidae Version 1.2 01/10/2005



Fish passage predictive model B for Cyprinidae, Fundulidae, Aphredoderdae, Gasterosteidae, Umbridae, Atherinidae, and Poeciliidae families. Based on physical measurements from Clarkin, K., et al. 2003. National inventory and assessment procedure for identifying barriers to aquatic organism passage at road-stream crossings. USDA Forest Service, San Dimas Technology and Development Center. San Dimas, CA. See attached figure detailing profile of survey points used in fish passage coarse filter. Elevation and distance measurements are in feet.

Figure 2. Fish passage model B.

Coarse Filter C Cottidae and Percidae Version 1.2 01/10/2005



Fish passage predictive model C for *Percina, Etheostoma*, Cottidae, Amblyopsidae, Elassomatidae. Based on physical measurements from Clarkin, K., et al. 2003. National inventory and assessment procedure for identifying barriers to aquatic organism passage at road-stream crossings. USDA Forest Service, San Dimas Technology and Development Center. San Dimas, CA. See attached figure detailing profile of survey points used in fish passage coarse filter. Elevation and distance measurements are in feet.

Figure 3. Fish passage model C.

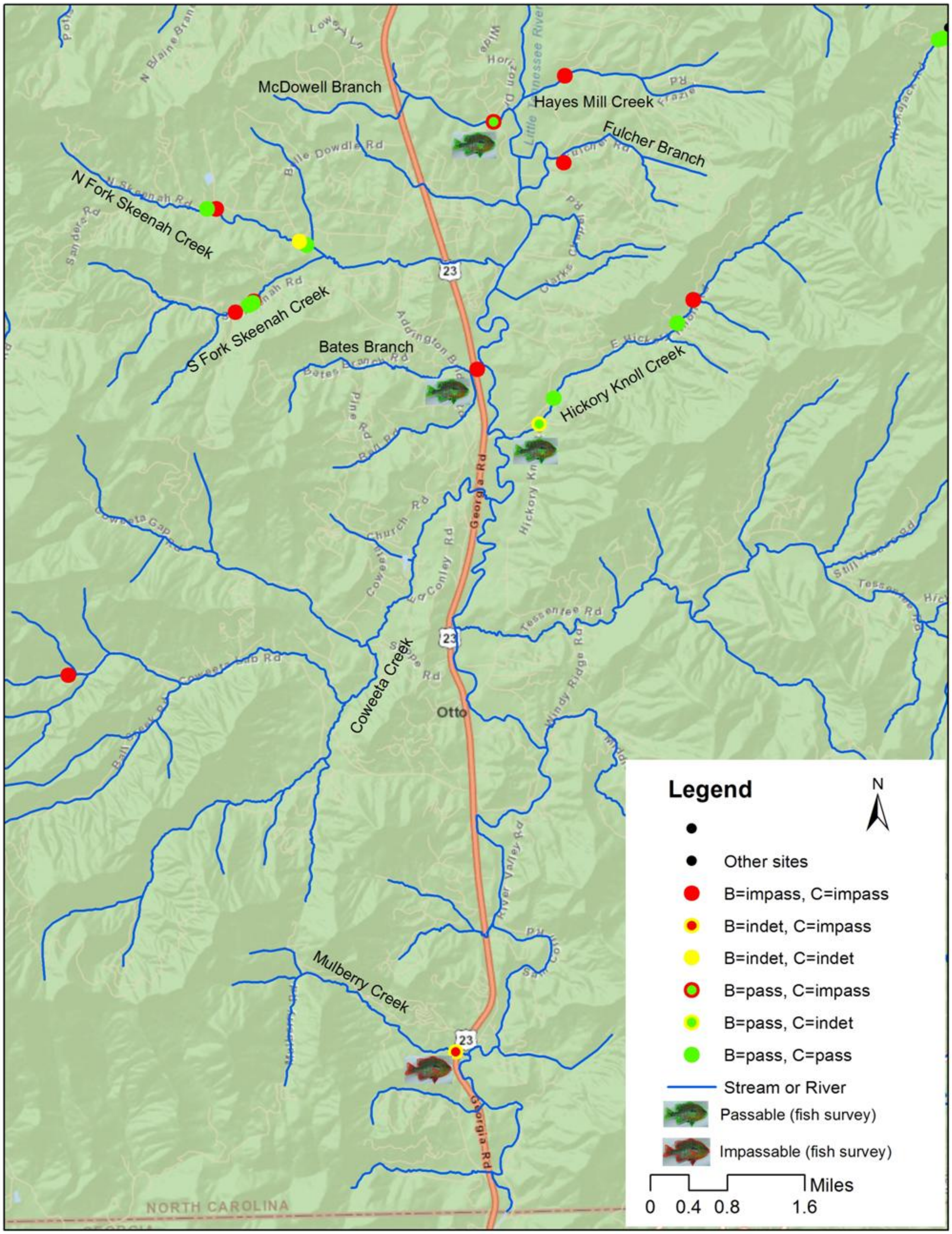


Figure 4. Study sites and passability determinations the mainstem Little Tennessee River basin.

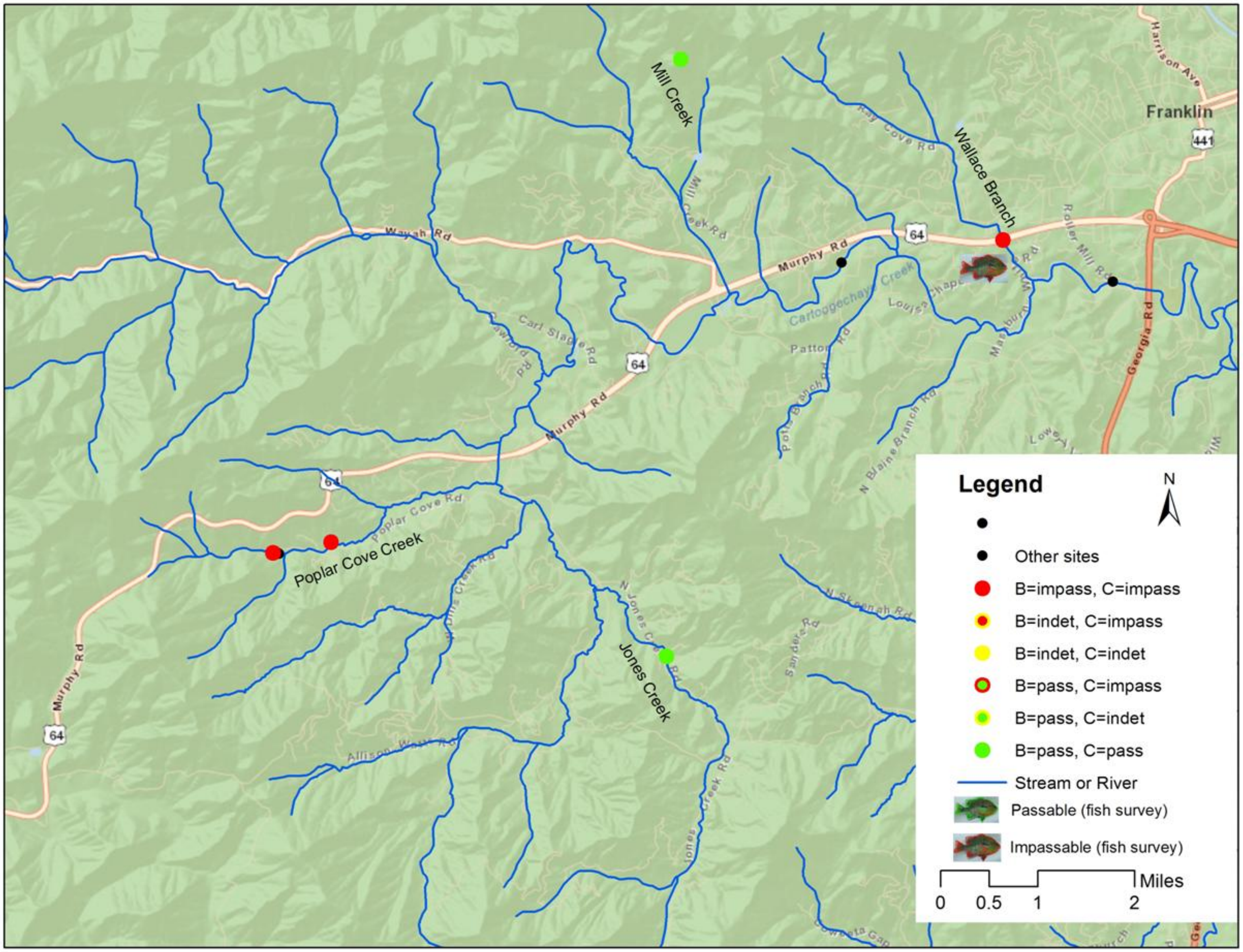


Figure 5. Study sites and passability determinations the Cartoogechaye Creek subbasin.

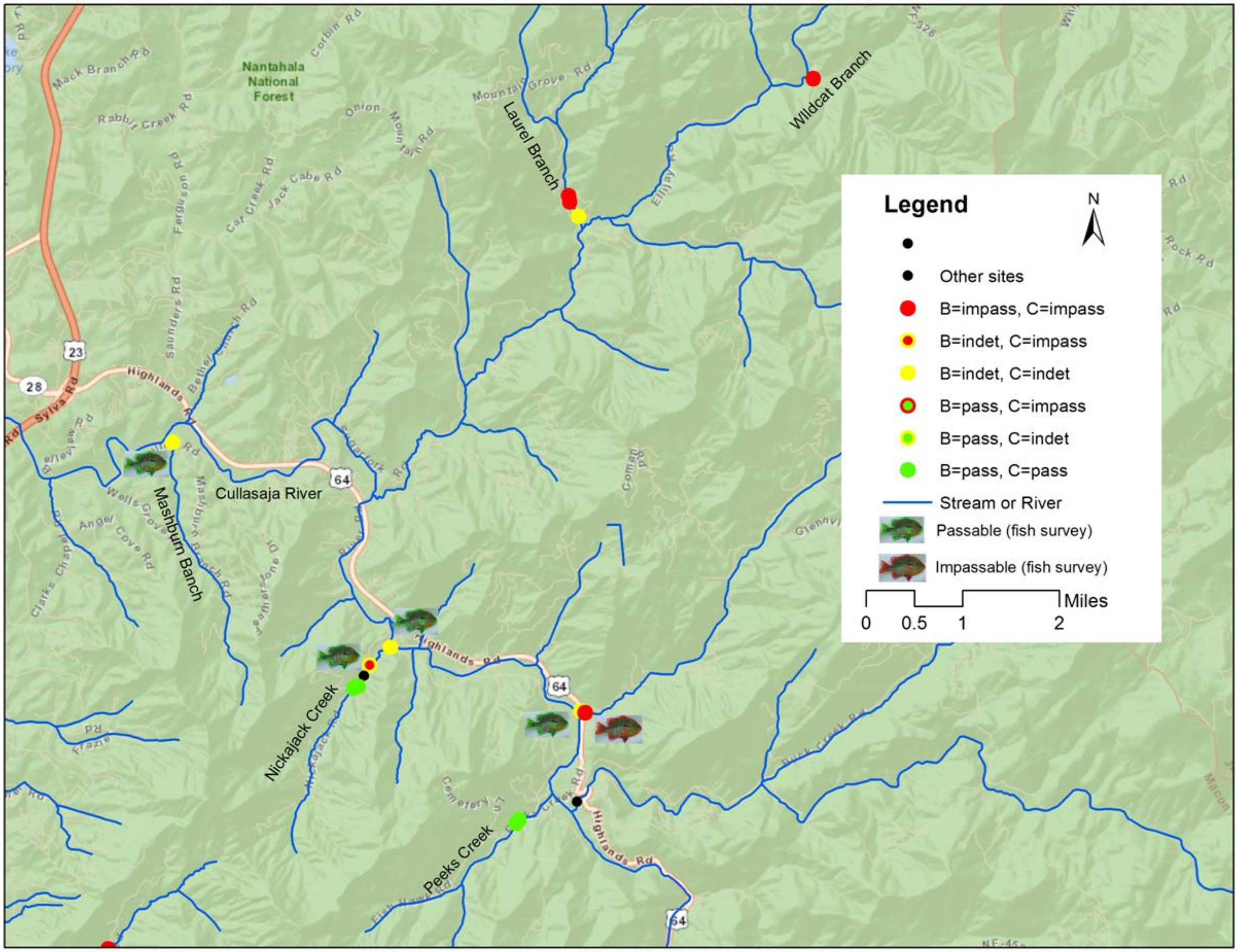


Figure 6. Study sites and passability determinations within the Cullasaja River subbasin.

Table 1. Physically surveyed structures and determination of passability.

Site Name	Stream	Locality	Passability	Reason for (Im)Passability
Mainstem tributaries				
Mul-A	Mulberry Creek	at US 441	Impassable	Slope x length =192
Cow-Sho-B	Shope Fork	USFS road (Shope Fork Rd)	Impassable	Drop = 17”, 2+ weirs
Bat-A	Bates Branch	at US 441	Impassable	Drop = 9.5”
Hic-A	Hickory Knoll Creek	at Hickory Knoll Rd (SR 1653)	Passable	Indeterminate for Filter C, slope x length = 21
Hic-B	Hickory Knoll Creek	at Slep Orchard Rd (private)	Passable	Backwatered
Hic-C	Hickory Knoll Creek	at E Hickory Knoll Rd (SR1643)	Passable	Slope x length = 8, thus passable
Hic-D	Hickory Knoll Creek	at Gorda Ln.(private)	Impassable	Drop = 14”
Ske-Sou-A	S.Fork Skeenah Creek	at SR 1128	Impassable	Indeterminate for Filter B. Drop = 6.7”
Ske-Sou-B	S.Fork Skeenah Creek	at Carolyn Dr	Passable	Backwatered
Ske-Sou-C	S.Fork Skeenah Creek	Private driveway off of S. Skeenah Rd (SR 1128)	Passable	Backwatered
Ske-Sou-D	S.Fork Skeenah Creek	at Upper Carolyn Dr (private)	Impassable	Slope = 4.5
Ske-Nor-A	N.Fork Skeenah Creek	at Whispering Meadows Dr (private)	Passable	backwatered
Ske-Nor-Aa	N.Fork Skeenah Creek	Private crossing off of Whispering Meadows Dr. (private)	Indeterminate	Slope x length = 93, debris jam at top of culvert
Ske-Nor-C	N.Fork Skeenah Creek	at Liberty Dr (private)	Impassable	Drop = 12.6”
Ske-Nor-D	N.Fork Skeenah Creek	Private crossing off of N Skeenah Rd (SR 1138)	Passable	backwatered
Ful-A	Fulcher Branch	at Clarks Chapel Rd (SR 1646)	Impassable	Perch = 39”
Hay-A	Hayes Mill Creek	at Pete McCoy Rd (SR 1728)	Impassable	Drop = 12.6”
Mcd-A	McDowell Branch	at Wide Horizon Dr (SR 1652)	Impassable	Drop =7”, passable for Filter B
Cartoogechaye Creek and its tributaries				
Car-Jon-A	Jones Creek	at N. Jones Creek Rd (SR 1128)	Passable	Slope x length = 13
Car-Pop-A	Poplar Cove Creek	at Buttonwood Dr (private)	Impassable	Drop = 12”
Car-Pop-Ba	Poplar Cove Creek	Private property at head of Poplar Cove Rd. (SR1304)		Tree in creek – filter does not apply

Car-Pop-Bb	Poplar Cove Creek	Private property at head of Poplar Cove Rd. (SR1304)		Blown-out bridge – filter does not apply
Car-Pop-Bc	Poplar Cove Creek	Private drive at head of Poplar Cove Rd. (SR1304)	Impassable	Slope = 7.5
Car-Mil-A	Mill Creek	at Mill Creek Rd (SR 1311)	Passable	Negative slope x length
Car-A	Cartoogechaye Creek	Access from Point Pleasant Rd (private)		Old dam remnants – filter does not apply
Car-C	Cartoogechaye Creek	Water plant, access from Industrial Park Rd (SR 1168)		Water company dam – filter does not apply
Car-Wal-A	Wallace Branch	at US 64	Impassable	Drop ~36”
Cullasaja River tributaries				
Cul-Buc-A	Buck Creek	Downstream from US 64		Old dam – filter does not apply
Cul-Pee-A	Peeks Creek	at Peeks Creek Rd (SR 1679)	Passable	Slope x length = 2
Cul-Pee-B	Peeks Creek	at Leebrook Dr (private)	Passable	Backwatered
Cul-Wal-A	Walnut Creek	at US 64	Indeterminate	Slope x length = 83
Cul-Wal-B	Walnut Creek	Private parking lot (Piney Grove Baptist Church)	Impassable	Drop = 28”
Cul-Nic-A	Nickajack Creek	at River Rd (SR 1672)	Indeterminate	Slope x length = 124
Cul-Nic-B	Nickajack Creek	at Nickajack Rd (SR 1674)	Impassable	Drop = 9”, indeterminate for Filter B
Cul-Nic-C	Nickajack Creek	Private- access from Nickajack Rd (SR 1674)		Dam type structure – filter does not apply
Cul-Nic-D	Nickajack Creek	at Nickajack Rd (SR 1674)	Passable	Backwatered
Cul-Nic-E	Nickajack Creek	at Glory Ln (private)	Passable	Backwatered
Cul-Eli-Wil-A	Wildcat Branch	at Ellijay Rd (SR 1001)	Impassable	Drop =9.7”
Cul-Eli-Lau-A	Laurel Branch	at Valley Rd (private)	Indeterminate	Slope x length = 34
Cul-Eli-Lau-B	Laurel Branch	at E Ridge Rd (private)	Impassable	Drop = 14”
Cul-Eli-Lau-C	Laurel Branch	at E Ridge Rd (private)	Impassable	Slope = 4
Cul-Mas-A	Mashburn Branch	at Fulton Rd (SR 1668)	Indeterminate	Slope x length = 45

Table 2. Indeterminate and Impassable crossings determined by physical assessment, and final determination based on biological sampling. CMP = corrugated metal pipe

Site	Name	Ownership	Crossing type	Passability (physical assessment)	Passability (biological assessment)	Drainage area above crossing (mi^2)	Distance to mainstem (mi)
Mainstem tributaries							
Mul-A	Mulberry Creek	DOT (US 441)	Triple box	Indeterminate (Filter B), Impassable (filter C)	Impassable	3.1	0.1
Cow-Sho-B	Shope Fork	USDA (USFS road)	1 box/ 1 CMP	Impassable	***	2.1	6.9
Bat-A	Bates Branch	DOT (US 441)	Triple box	Impassable	Passable	2.5	<0.1
Hic-A	Hickory Knoll Creek	DOT (SR 1643)	CMP	Passable (Filter B), Indeterminate (Filter C)	Passable	5.2	0.4
Hic-D	Hickory Knoll Creek	private driveway	CMP	Impassable	#	2.5	2.7
Ske-Sou-A	SF Skeenah Creek	private driveway	CMP	Impassable	***	2.9	3
Ske-Sou-D	SF Skeenah Creek	private driveway	CMP	Impassable	***	2.3	3.2
Ske-Nor-Aa	NF Skeenah Creek	private	CMP	Indeterminate	#	3.5	2.3
Ske-Nor-C	NF Skeenah Creek	private driveway	CMP	Impassable	NG	2	3.4
Ful-A	Fulcher Branch	DOT (SR 1646)	CMP	Impassable	#	1	0.2
Hay-A	Hayes Mill Creek	DOT (SR 1728)	Pipe-arch	Impassable	#	1.6	0.4
Mcd-A	McDowell Branch	DOT (SR 1652)	CMP	Passable (Filter B), Impassable (Filter C)	Passable	1.6	0.3
Cartoogechaye Creek and its tributaries							Distance to Cartoogechaye Creek
Car-Pop-A	Poplar Cove Creek	private driveway	CMP	Impassable	***	2.3	1.7
Car-Pop-Bc	Poplar Cove Creek	private driveway	CMP	Impassable	***	1.5	2.2
Car-Wal-A	Wallace Branch	DOT (US 64)	Triple box	Impassable	Impassable	3.2	0.4
Cullasaja River and its tributaries							Distance to Cullasaja River
Cul-Wal-A	Walnut Creek	DOT (US 64)	Triple box	Indeterminate	Passable	6	<0.1
Cul-Wal-B	Walnut Creek	church parking lot	Triple box	Impassable	Impassable	6	<0.1
Cul-Nic-A	NIckajack Creek	DOT (SR 1672)	CMP	Indeterminate	Passable	2.8	<0.1
Cul-Nic-B	Nickajack Creek	DOT (SR 1674)	CMP	Indeterminate (Filter B), Impassable (Filter C)	Passable	2.5	0.3
Cul-Eli-Wil-A	Wildcat Branch	Private driveway	CMP	Impassable	***	4.3	7.4
Cul-Eli-Lau-A	Laurel Branch	Private driveway	CMP	Indeterminate	***	2.7	4.3
Cul-Eli-Lau-B	Laurel Branch	Private driveway	CMP	Impassable	***	2.7	4.5
Cul-Eli-Lau-C	Laurel Branch	Private driveway	CMP	Impassable	***	2.7	4.5
Cul-Mas-A	Mashburn Branch	DOT (SR 1668)	CMP	Indeterminate	Passable	2.1	<0.1

*** : did not assess using biological methods due to time limitations

: low fish counts upstream, suggesting either a filter-type barrier, or poor habitat.

NG : Access permission not granted by landowner

Appendix. Field sheet

Initials of crew:	Time/Date:	County, State:	Site #:
Stream name:	Land ownership:		
Locality:			
Projection should be WGS 84	UTM 17	E:	N:
Weather:	Base flow (high, average, low):		
Crossing Type: Box / Pipe / Open-bottom arch / Pipe-arch / Freespan / Ford / Vented ford / Other:			
Structure Type: Concrete / Corrugated metal / Smooth metal / Wingwalls / Headwalls / Apron / Number of openings:			
Describe crossing:			
Culvert embedded / perched, describe:			
Presence / size of sediment in culvert:	Rust line: (ft)		
Culvert Height X Width ***or*** Diameter:	Culvert length:		
Scour pool depth X width X length **DS**:	**US**:	Depth of water in culvert/crossing:	

	Wet Width		Sed. Width		Top to Water		Top to Sed		Lip to water surface		Lip to streambe d	
	US	DS	US	DS	US	DS	US	DS	US	DS	US	DS
RL												
ML												
MR												
RR												

	Riparian cover (< 30m from stream edge)	Bank height	Bank cover (nearest 5%; ≤ 2m from stream edge)	Bank erosion (Y/N)
DS RL				
DS RR				
US RL				
US RR				

CR=Cropland PA=Pasture FM=Farmstead SI=Silviculture GR=Grassland SW=Shrubs or woodland RR=Rural Residence UR=Urban residential/commercial UI=Urban industrial

	Max stream width adj to culvert	Avg stream width, away from culvert impact area, ≈25-100m away
US		
DS		

Stream bed texture mostly: sand (< .08 in)/ gravel (0.08 – 2.5 in)/ cobble (2.5 – 10 in)/ boulder (> 10 in) / bedrock.
Describe embeddedness for both US and DS:

Is there erosion or bank instability around the culvert or US / DS of the culvert in the culvert impact area (≈ 0-25m from culvert)? Describe:

Is the culvert set parallel to stream flow?

Are there bars / excessive sediment deposition US of the culvert in the impact area compared to DS, away from the culvert? Describe:

General notes:

***At least 6 photos** per site: US & DS from road of the stream reach & looking US & DS at culvert from in the stream.*

Notes on additional descriptive photos:

Defined tailwater pool (circle): **Present / Absent**

Survey

Station	BS (+)	FS (-)	Elevation	Notes
			100.00	

P_1 Culvert inlet
P_2 Culvert outlet
P_3 Tailwater control

** Station: The distance (ft) along the profile or transect from the starting point.

Culvert slope: _______ % $\frac{\text{elev } (P_1 - P_2)}{\text{dist } (P_1 - P_2)} \times 100$

Outlet drop: _______ (elev P_2 – elev P_3)

Culvert length: ______ (dist P_2 – dist P_1)

Structure backwater entire length of pipe: _______ (elev P_3 – elev P_1)

**On a separate sheet, make a sketch of the site characteristics.