INDEX OF BIOTIC INTEGRITY (IBI) AND SPECIES INVENTORY OF THE FISH ASSEMBLAGE OF BETTY CREEK (LITTLE TENNESSEE RIVER WATERSHED, RABUN COUNTY, GEORGIA) AT THE HAMBIDGE CENTER PROPERTY, FOLLOWING RESTORATION ACTIVITIES: YEAR 4 (2014).

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TABLE OF CONTENTS

HAMBIDGE 2014 REPORT – EXECUTIVE SUMMARY

In 2014, the LTLT Stream Biomonitoring team (formerly the LTWA team), with the help of 17 community volunteers (total of 99 volunteer hours), replicated our 2011 studies of the fish assemblage in the reach of Betty Creek on the property of the Hambidge Center for Creative Arts and Sciences. These surveys aim to provide the Hambidge Center with baseline information on aquatic biodiversity on their property, but more particularly to help evaluate the progress of an ongoing stream restoration project initiated in 2010 by Golder and Associates.

The goal of the restoration work is to arrest and correct the development of conditions on two reaches of Betty Creek (here referred to as the upper and lower restoration reaches) which were potentially impacting biodiversity and damaging the esthetic of the stream at and downstream of the directly affected areas. Problems included continual erosion of banks with attendant sedimentation at and downstream of the eroding bank, loss of significant portions of the riparian vegetative buffer and replacement of natural riffle/pool sequences with variable depth by unproductive shallow riffles and runs.

While the esthetic condition of the stream and channel and bank stability can be judged on the basis of visual inspection, biodiversity can be more difficult to assess, and is often not included in budgeting for stream restoration projects. Given that data collected by LTLT over 25 years have demonstrated that Betty Creek is the single healthiest of all tributaries draining more than 4 mi^2 to the Little Tennessee River above Fontana Reservoir, plus the Hambidge Center's commitment to conservation, it was important to include biological assessment in the restoration plan. Golder and Associates and the Hambidge Center are to be commended for supporting this ongoing project.

Following a baseline fish species survey of Betty Creek on the Hambidge Center property, carried out in 2010, we have revisited Betty Creek in the summers of 2011 and 2014. On each occasion, we carried out 3 fish samples using an Index of Biotic Integrity (IBI) protocol, which results in both a complete species inventory and development of an index, which in turn permits us to assign a Bioclass Rating (Very Poor, Poor, Fair, Good or Excellent).

Samples included two "restoration reaches" bracketing and including two areas where Golder and Associates carried out instream restoration activities in 2010 and again in 2012 (hereafter referred to as the "intervened areas"). The third sample site, located just upstream of the upper restoration reach, is a reference site in the least anthropogenically impacted area of Betty Creek on the Hambidge Center property; this same reference site was used by Golder as a baseline for the restoration effort.

Apart from continuing biological inventory, the purpose of the monitoring effort has been to assess the success of the restoration work in enhancing the ecological health (biotic integrity) of the fish assemblage and, by inference, the stream as a whole. In so doing, two facts need to be kept in mind:

1. While it may be relatively easy to enhance ecological health in a heavily impacted stream, it is difficult to achieve significant biological enhancement in a high quality stream such as Betty Creek. In biological terms it is fair to think of Golder's work as more preventive than restorative.
2. Restoration projects do not exist in a vacuum. Betty Creek at the Hambidge Center is continually subject to any number of positive and negative anthropogenic and natural impacts originating on the property and elsewhere in the watershed, which may override or mask effects of restoration activities.

Fortuitously, LTLT and the Hambidge Center have prior fish inventory and IBI data from a portion of Betty Creek corresponding to the upper restoration reach from prior years (1996, 2003

and 2008) as well as data from elsewhere on Betty Creek going back to 1990. The IBI data suggest a gradual decline in ecological health beginning in the late 90's, followed by recovery beginning between 2003 and 2008; present conditions approximate those determined in 1996. We can only speculate as to the causes of this trend, but it corresponds to the history of upstream sources of pollution and sediment. The continual high water of 2013 may also have served as a "reset", accelerating recovery through flushing of accumulated sediment.

Any physical intervention in a stream channel, even though the long term intent is improvement, will negatively impact the biological condition of the stream. This was what we found in 2011, as instream work in the fall of 2010 contributed to drops in the IBI for both restoration reaches, with the upper restoration reach declining from a Good to a Fair Bioclass Rating.

However, certain aspects of the 2010 restoration work can be judged as failures, both structurally and biologically. These conditions were corrected in 2013, probably aided by the high flows of that year, and in 2014 IBI at all 3 sites rebounded to 1996 levels (Good Bioclass Rating).

In addition to completing species inventory and calculating IBI's, we kept separate data for the physically intervened portions of the restoration reaches, which permits us to draw conclusions about the effects of the initial effort and the modifications made in 2013. We note that:

- Excessive abundance of contamination-tolerant and omnivorous fish species (associated with large areas of slow moving water and sandy/silty substrates) has returned to normal levels.
- Levels of parasite infection, associated with large expanses of soft substrate, which arose in 2011 have returned to normal background levels.
- In 2011, the relative abundance of fish species which depend on the swift flow and cobble substrate typical of Betty Creek was significantly lower in the intervened areas; it has returned to normal.
- There are still apparent effects of the lack of shade and tall riparian vegetation in the intervened areas. (This was also the case for these areas pre-restoration.) Assuming good survival and growth of planted and volunteer trees, this situation will correct itself in the years to come.

In addition to the IBI results, we note 2 positive and 2 negative trends, 3 of which may or may not be related to the restoration work:

- Both increased size of adult trout and higher survival of juveniles were noted in 2014.
- The greenfin darter, a regional endemic which was absent from the Georgia waters of the Little Tennessee River for many years, returned to Betty Creek in 1996 and is expanding its numbers on the Hambidge Center property.
- Numbers of the watershed endemic Tuckasegee darter were alarmingly low in 2014.
- In 2014 for the first time we captured juveniles of a new invasive exotic, yellow perch, which could become a severe competitor with trout and native fishes. (This change is definitely not related to restoration work.)

The main factor impacting the biological health of Betty Creek, as in most streams in populated areas, is elevated levels of fine sediments in the substrate. Restoration work at Hambidge can effect modest improvement in this situation, but significant change would require watershed-wide changes in land management. With that caveat, our work confirms the importance of Betty Creek in maintaining biodiversity in the Little Tennessee watershed, and the role of stewardship by the Hambidge Center in protecting it. If by the planned end of the restoration project in 2018 we still encounter full species diversity, high IBI scores (Good Bioclass Rating) and a healthy, diverse riparian vegetative buffer throughout, the restoration project can be judged a success.

INTRODUCTION

The present document is the third in a series of reports tracking the response to in-stream restoration work on the fish (and crayfish) assemblage of Betty Creek where it bisects the property of the Hambidge Center for Creative Arts and Sciences (Little Tennessee River watershed, Rabun County, Georgia). Our first report provided a baseline inventory of fish and crayfish species over the length of Betty Creek at the Hambidge Center. A second report assessed the ecological health of two reaches of the creek where restoration work, including reconstruction of portions of the channel and vegetation planting, was undertaken in December, 2010, and compared them to an unmodified reference site.

Our initial hypothesis was that, following the baseline survey, we would track the response of the fish assemblage to instream work, with the anticipation of an unavoidable temporary negative effect, followed by recovery over time. If the restoration were to prove to be completely successful, we would observe gradual improvement; by about 2020 the condition of the stream within and near the two restoration reaches would be biologically indistinguishable from the reference reach.

This timeline was altered by the failure of certain aspects of the initial work in both restoration reaches, necessitating a second round of instream work, which was carried out in the fall of 2013. The shape of pools was reconfigured, and bank erosion was addressed through additional construction under an Adaptive Management Plan (AMP). The AMP work involved reconstruction of the stream banks to install "toe wood" structures at two of four banks where erosion was the most pronounced, and vegetated sod mats on the other two banks to accelerate vegetative growth. Log vanes were also installed; two each at all four reconstructed stream bank locations in the adjacent reconstructed pools. Live willow stakes (*Salix nigra*), live willow brush packs, and sycamores (*Platanus occidentalis*) were also installed, concurrent with work to suppress invasive exotic vegetation.

This report will closely follow the format of McLarney, et al. 2012; it is essentially a second "post-impact" report. Before proceeding to a discussion of methods and results it may be helpful to repeat and update some introductory remarks from our 2012 report.

With regard to fish-based assessment of the effects of restoration efforts, the Hambidge Center site presents one great advantage and an equally significant disadvantage:

We have the unique advantage of being able to draw on a large volume of prior data. During 1990-2014, the senior author has directed and analyzed 49 fish samples at 13 sites on Betty Creek between the extreme upper reaches in the Southern Nantahala Wilderness (River Mile 7.4) and a point just below the US 441 bridge in Dillard, Georgia (River Mile 0.6), plus 21 samples on 8 tributary streams (including Patterson and Barkers Creeks, on the Hambidge Center property). Data from Betty Creek and the rest of the upper Little Tennessee watershed since 1990 may be accessed electronically (http://coweeta.uga.edu/dbpublic/dataset_details.asp?accession=LTWA_2010_06_01).

Some of these samples were at the level of species inventory, but about half have been made using an Index of Biotic Integrity (IBI) protocol, which results in a numerical rating of the health of the stream while virtually assuring complete and proportional representation of fish species. Three previous IBI samples (in 1996, 2003 and 2008) have been carried out on a reach of Betty Creek which includes the upper restoration site sampled in 2011 and 2014.

We are thus able to supplement fish inventory results with numerical measurement of ecological health, leading to assignation of a Bioclass Rating along a scale of Very Poor to Excellent. (Table 1 describes the general attributes of the fish assemblage at stream sites with different Bioclass Ratings.) This information will be particularly useful in tracking the progress of the upper restoration reach.

The disadvantage is perhaps one we should not dwell on too much. Historically IBI in Betty

Creek, on and off the Hambidge Center property, has with few exceptions been high (Bioclass Rating Good). This includes a 2014 assessment at our lowermost site (RM 0.6). Thus there is relatively little room for measurable improvement.

Changes in Bioclass Rating along the Poor-Fair-Good continuum are common and may include measurable effects of restoration work. However, Excellent ratings are normally associated with pristine, undeveloped watersheds; upgrading a stream from Good to Excellent is very difficult. Thus, while in this report we will compare IBI on all 3 reaches with results from 2011 (and where applicable, previous years) emphasis will be on:

1. The fish assemblage within the intervened areas (which are too short to permit calculation of a separate IBI)
2. The response of individual fish species and species groups.
3. Placing the Hambidge Center reach within a larger context of trends in Betty Creek as a whole.

METHODS

During June 9 – July 24 the LTLT Biomonitoring Team, with the assistance (on different days) of 17 community volunteers carried out 3 samples of the fish assemblage on Betty Creek at the Hambidge Center, using an IBI protocol, which provides data for ecological assessment simultaneously with achieving what is normally a complete fish species inventory. The fish data was supplemented with counts and identification of crayfish. (See discussion below.)

Capture of fish was accomplished through the use of two backpack electrofishers in conjunction with a seine (20 ft. long, 4 ft. deep, 3/16 inch mesh) placed across the stream at intervals, and up to 6 hand dip nets. Over the course of each monitoring reach we carried out 9-10 subsamples, for which data were recorded separately, thus permitting not only an overall assessment at each of the 3 sampling sites, but observations on the use of different habitats by the various species. Upon completion of each subsample, fish were released downstream to prevent recapture and double counting.

We monitored the same 3 reaches as in 2011. Two of them corresponded to the restoration sites surveyed in fall, 2010 and bracketed the portions of the creek where physical intervention occurred. The third monitoring reach was a reference reach, initially selected by Golder and Associates as offering the best habitat conditions along Betty Creek on the Hambidge Center property. This reach, which features full riparian cover and absence of conspicuous bank erosion or other on-site anthropogenic impacts, commenced just above the upstream end of the upper restoration reach. Site selection was also guided by criteria specific to IBI sites. These include:

- Minimum 2 bends or 2 riffle-pool sequences.
- Representation of all types of available habitat, including small features such as backwaters, side channels, etc.
- Sample reach length at least 15 X average stream width.
- Presence of all “expected” species (or a logical explanation for their absence).
- Minimum 200 individual fish, for statistical reasons.

Note that the last 2 criteria can only be determined during the sampling process. Table 2 documents the achievement of quantitative IBI site criteria, along with other measures of effort. Note that for the restoration reaches we were able to reduce sample length and time, while still achieving a sample length/width ratio >15 and capturing all expected species.

In this report we will consider the results of these 3 samples in the context of species inventory (compared with multiple previous efforts on and off the Hambidge Center property) and also in the

context of ecosystem health as measured by IBI. Comparisons will be made between 2011 and 2014 results and, in the case of the upper restoration site, with 3 pre-restoration IBI samples on that reach, spread over a period of 13 years. For both restoration sites, we will be able to compare 2011 and 2014 IBI and inventory data with results from the reference site. Because of the way in which the sampling was designed, we will also be able to track changes on the intervened stream sections separately from the rest of each "restoration site". Given the alterations to the restoration effort made in 2013, this comparison will be particularly meaningful. As baseline information, we include an annotated list of all the fish species known to exist in Betty Creek on the Hambidge Center property (Table 3).

A NOTE ON CRAYFISH

Crayfish (Decapoda) are the "orphans" of biomonitoring. Although they fit under the definition of "macroinvertebrate", most benthic ecologists focus primarily on insects and treat these largest "bugs" as peripheral in doing stream health assessments. While crayfish are readily captured using standard fish sample methods, they are not normally taken into account in developing IBI criteria and so tend to be ignored during fish samples.

Nevertheless, crayfish are conspicuous members of our stream fauna and are of particular interest in terms of biodiversity conservation due to their prolific speciation, with endemic species in many watersheds. In the upper Little Tennessee watershed, below elevations of 3,000 feet, we have 2 species of crayfish. *Cambarus bartoni* (Appalachian brook crayfish) is widespread and abundant in most watersheds arising along the Appalachian chain from New Brunswick to north Georgia. *Cambarus georgiae* (Little Tennessee River crayfish) on the other hand has a very restricted range, being limited to the upper Little Tennessee watershed upstream of Franklin, NC (plus Burningtown Creek in northern Macon County, North Carolina).

Due to its restricted range and the paucity of information on the latter species in 2011 the North Carolina Wildlife Resources Commission and the U.S. Fish and Wildlife Service requested the LTWA (now LTLT) Biomonitoring Team to keep records on crayfish taken during our IBI work. Accordingly, we have been counting individuals of both species. Both were taken at all 3 Hambidge Center sites in both years, and will be included in the discussions which follow.

SITE DESCRIPTIONS

The reader interested in full site descriptions is referred to our 2012 report. Here we will concentrate on differences between the 2011 and 2014 versions of the 3 sites. The only significant difference between the two years is that both of the restoration reaches were considerably shorter in 2014. Given the minimum length criterion of 15X mean width, it was not feasible to treat the 2 intervened areas as separate IBI sites, so additional lengths of stream immediately downstream (lower restoration site) or bracketed by 2 intervened sections (upper restoration site) but not directly impacted during instream work, were added to provide adequate length. In 2011 the lengths of additional, unaltered stream were themselves long enough to constitute an IBI sample reach, but this was not the case in 2014. Examination of the 2011 data revealed no significant difference if data from these unaltered areas were treated separately or combined with data from the intervened areas, so total sample lengths were reduced while still containing the requisite 2 riffle/pool sequences.

Changes within the intervened areas are readily apparent from even casual observation. Both the initial restoration and the modified version of 2013 focused on sloping and stabilizing eroding banks and revegetating the riparian area. The initial effort created large, round, wide pools with few in-pool habitat features. This resulted in large areas with low flow which accumulated silt and sand, providing habitat chiefly for tolerant and omnivorous fish. The more recent version narrows the channel, creating

flowing pools with some internal structure, with virtually no "dead" water. An added benefit in the lower restoration reach is the elimination of a section of shallow, braided channel at the upstream end.

At this time the major difference between the intervened and non-intervened areas is the absence of riparian shade on the intervened areas. Assuming a combination of good survival of planted trees and natural revegetation, riparian conditions in the intervened areas will begin to resemble those on the rest of the Hambidge Center reach by the end of the project period.

Table 4 shows some physical characteristics of the 3 sample reaches in 2011 and 2014. The two restoration reaches include both intervened and non-intervened areas. Note the reduction in area due to narrowing of the channel in the intervened areas. For both restoration areas in both years, maximum depth was found in the newly created pools.

RESULTS AND DISCUSSION

Results will be presented in terms of 1) species inventory, 2) application of the IBI and 3) changes in the intervened areas. Comparisons will be made between years and areas and with other monitoring sites, as appropriate. This categorization will occasion some level of redundancy, but seems essential to fully communicating the results of our work and providing an informational base for the Hambidge Center and others.

Species inventory:

Table 5 shows the results of our monitoring expressed as the total number of each species in the 3 sample reaches. Results for the two restoration reaches are divided into intervened and non-intervened sectors. Comments on species and species groups will follow the pattern set in our two earlier reports. In our 2012 report we mentioned 4 species of fish which have been reported from the Hambidge Center reach of Betty Creek in the past, but which have not appeared during the course of this project. One of these species (yellow perch, *Perca flavescens*) was taken in 2014 and will be discussed below. The other three (white sucker, *Catostomus commersoni;* golden redhorse, *Moxostoma erythrurum* and Largemouth bass, *Micropterus salmoides)* did not appear in 2014 and are omitted from tables and discussion.

Other than yellow perch, no "new" species appeared in 2014. Of 27 species reported in 2012, 6 were not captured in 2014. Of these, whitetail shiner (*Cyprinella galactura*) and black redhorse (*Moxostoma duquesnei*) are seasonal migrants, and would not normally be expected in Betty Creek in the summer. Two species, redbreast sunfish (*Lepomis auritus*) and spotted bass (*Micropterus punctulatus*) are undesirable exotics normally associated with streams warmer than Betty Creek. While bluegill (*Lepomis macrochirus*) are native to the area, bluegills found in small streams are likely to be farm pond escapees rather than permanent parts of the fauna. A single olive darter (*Percina squamata*) can best be described as a "spectacular stray"; establishment of a population of this rare species in Betty Creek seems unlikely. All of these fish were found in very small numbers (1-6 individuals in the 3 sample reaches combined); their absence in our 2014 samples does not indicate anything about the health of Betty Creek at the Hambidge Center.

If the numbers in Table 5 are compared with the similar table from our 2012 report it will be noted that the total number of fish is down for all 3 sample reaches, and for both intervened and non-intervened sectors. The same holds true for most species; in 57 of 71 instances where a species appeared in a sample reach, its numbers were lower in 2014. This should not be construed to have significance with regard to the health of Betty Creek. In 2014 we noted reduced total numbers of fish at the great majority of our sampling stations in the upper Little Tennessee watershed. This is part of a normal cyclic pattern, which in this case we take to be related to displacement of fish by almost continual

high water levels during most of 2013. This effect is undoubtedly exaggerated to some degree by the smaller sample area in the restoration reaches; however total fish catch also dropped from 711 to 653 in the reference reach where the 2014 sample area was slightly larger. Some decreases – and increases – in species abundance between 2011 and 2014 likely are significant and will be discussed in the following section.

In our comments on individual species and groups of fish which follow, we will not repeat all of the background material presented in our previous report. The reader may wish to consult that report if the significance of certain groupings is not apparent.

Mountain brook lamprey (*Ichthyomyzon greeleyi*) In our previous report we commented on the greatly increased abundance of this filter-feeding species, with concentration in the muddy shallows of the newly created pools at the restoration sites. The changes made in 2013 have resulted in numbers of lampreys more in line with what would normally be expected in Betty Creek. Of a total 121 lampreys taken from the restoration reaches in 2011, 104 (86.0%) came from the newly constructed pools. In 2014, we took only 13 total from the restoration reaches; 9 (69.2%) were from the intervened areas.

Trouts: This is the group of fishes which has most clearly increased between 2011 and 2014. Rainbow trout (*Oncorhynchus mykiss*) in our samples increased from 32 to 46, and brown trout (*Salmo trutta*) from 6 to 34. Of these 80 individuals, 12 were over 100 mm. long and were measured to provide an indicator of the value of the sport fishery. These data are presented in Table 6. The data suggest 3 observations:

- The size distribution of adult trout of both species is similar, although the largest individuals of both species exceeded the length of the largest from 2011.
- The increase in trout numbers is entirely due to juveniles; suggesting favorable conditions for reproduction in recent years.
- This year, as opposed to 2011, the larger trout are concentrated in the upper restoration reach, in the newly constructed pool area, but also in natural pools within this reach. In this same reach we observed exceptional numbers of mottled sculpin (*Cottus bairdi*) a favored forage species, especially for large brown trout.

Nutrient-dependent cyprinids: As noted in our previous report, all 3 of the species in this category (central stoneroller, *Campostoma anomalum*; river chub, *Nocomis micropogon*, and creek chub *Semotilus atromaculatus)* increased their individual and collective abundance 3-fold in Betty Creek in the area of the upper restoration site between 2003 and 2008. At the time we suggested that "a desirable restoration goal would be to return the proportion of nutrient-dependent cyprinids to something approaching 2003 levels." However, the initial intervention in the channel apparently had the opposite effect, resulting in record abundance of all 3 species.

Our data further showed that the 3 species taken together were 2.6-2.7 times as abundant at the restoration sites as compared to the reference reach. While there is a decline in abundance of all 3 species in 2014 as compared to 2011, the discrepancy is even greater; the restoration reaches currently have 4.6-4.8 times as many nutrient-dependent cyprinids per area as in 2011.

While oscillations in total fish abundance make it difficult to interpret the data, it appears that river chub and creek chub abundance is returning to lower levels, while stoneroller abundance is nearly double that in our 2003 sample and more than 7 times greater than in a 1996 sample. Trends in abundance of all 3 species depend not only on land management at the Hambidge Center, but also on human activity upstream of the property. To the degree that restoration activity can affect this aspect of biotic integrity, two factors enter into play:

- Increased rates of sediment deposition (as inevitably occurs during and following in-stream work) favor river chubs and creek chubs over other cyprinid species (shiners and smoky dace) with which they share the water column. As new sediment is dispersed, and stabilization and revegetation of the banks takes hold, rates of sedimentation will decline.
- Stonerollers are dependent on algal pastures, growth of which, in addition to nutrients, requires insolation. As shade develops along the restored areas, production of benthic algae will drop, and so should the abundance of stonerollers.

While we cannot predict what will happen with regard to nutrient and sediment sources located upstream of the Hambidge Center, the trend in terms of this group of fish, characteristically overabundant in streams with heavily developed watersheds, should be downward.

Smoky dace (*Clinostomus sp*.) In our previous report we noted that this intolerant insectivore was "holding its own" in Betty Creek. Based on 2014 data, it is more than holding its own, with numbers almost double those reported in 2011. There is no apparent explanation for this phenomenon, but it seems unlikely that it is related to the restoration effort.

Native shiners: The warpaint shiner (*Luxilus coccogenis*) enjoyed a brief spurt of population growth in response to the first restoration effort. While warpaint shiners are associated with forested watersheds, one or two large open pools in an otherwise shaded stream create ideal feeding stations. With the narrowing of and increased flow through the pools in the intervened reaches warpaint shiner numbers appear to be returning toward normal.

The other two native shiners, the Tennessee shiner (*Notropis leucodius)* and the mirror shiner (*Notropis spectrunculus*) are difficult to read in the context of Betty Creek. The Tennessee shiner seems to reach the upper end of its normal range somewhere within the Hambidge Center property and has never been common in the reference reach, while the mirror shiner, in Betty Creek and elsewhere, displays "boom and bust" population fluctuations apparently independent of environmental variables. In both cases the result is to obscure any possible reaction to restoration activities.

Yellowfin and hybrid shiners: The invasive exotic yellowfin shiner (*Notropis lutipinnis*), first detected at the Hambidge Center in 2003, seems to be at the upper end of its range in upper Betty Creek where its population has not exploded as in some valley streams, including lower Betty Creek. While, as in previous years we encountered yellowfin hybrids (with smoky dace and Tennessee shiner), numbers are too low to permit any discussion of trends.

Catostomids (suckers): In the past two years we have encountered very few redhorses (*Moxostoma* spp.) in Betty Creek in the summer; the only expected catostomid is the northern hogsucker (*Hypentelium nigricans*), which seems to be holding its own, with no discernible effect of restoration activities.

Centrarchids: In 2011 we observed two pollution-tolerant sunfishes, the exotic redbreast sunfish (*Lepomis auritus*) and the native green sunfish (*Lepomis cyanellus*) in unprecedented numbers in the newly constructed pools in the restoration reaches, not only along the shoreline, but in mid--pool. In 2014 the redbreast sunfish was absent from the sample and the green sunfish was back to normal proportions and found only over small patches of muddy substrate along the shoreline of pools.

Our one intolerant centrarchid, the rock bass (*Ambloplites rupestris*) appears to be holding its own. No relationship with restoration activities is apparent.

Yellow perch (*Perca flavescens*) is not native to the upper Little Tennessee watershed, and was first documented from the watershed in 1995, although we have a visual record from 1988. It has radiated outward from a stronghold in Lake Emory at Franklin, NC, and was reported from Betty Creek (at the Hambidge Center) in 2008. Until 2014 all perch reported from above Lake Emory have been adults, but in that year we took numbers of juvenile yellow perch from pools in Betty Creek at the Hambidge Center, and also from the Little Tennessee in the parallel Wolf Fork Valley, suggesting that the species is well established in the upper watershed. If they become abundant, young yellow perch will be strong competitors with small native insectivores, both benthic and column feeders, and the adults will compete with trout and rock bass.

Benthic insectivores: As data from the reach containing the upper restoration area in Table 7 suggest, benthic insectivores have been on the decline in upper Betty Creek for some time but made a comeback between 2011 and 2014, based on increased numbers of the single dominant fish species in Betty Creek, the mottled sculpin (*Cottus bairdi*). Among the other benthic insectivores, including 3 species of darters and 2 of cyprinids, numbers are too low to permit confident statements about trends. (Clarification: Based on studies of its diet, the mottled sculpin merits being termed an "insectivore". However, for purposes of IBI it is not a "specialized insectivore", because its' very large mouth enables it to eat substantial amounts of crayfish, juvenile fish and other non-insect foods.)

On the positive side, we note what appears to be the continued upstream spread of the regional endemic greenfin darter (*Etheostoma chlorobranchium*) which was apparently absent from the Georgia waters of the Little Tennessee watershed from the late 60's until the early 90's, first reappeared in Betty Creek in 1996 and on the Hambidge Center property in 2009. And there was a noticeable increase in abundance of the longnose dace (*Rhinichthys cataractae*) in the reference reach in 2014.

On the other hand, the proportion of darters (4 species reported) appears to be declining. We are particularly concerned about the rarity of the watershed endemic Tuckasegee darter (*Etheostoma gutselli)* represented in 2014 by a single specimen from the unintervened section of the lower restoration reach.

In our previous report we suggested a negative relationship between abundance of benthic insectivores and that of the central stoneroller, with which benthic insectivores compete for physical habitat, though not for food. Stonerollers are favored by reduction of riparian shade, which was occurring over the two restoration areas before the inception of the restoration project, and by high nutrient levels. Benthic insectivores are favored by reduced amounts of sediment in the rocky substrate. We suggest that the trends suggested by the data in Table 7 may be attributable to 3 factors:

- Increase in the amount of substrate available for photosynthesis and development of algal pastures, which was occurring where eroded stream banks were left without shade. This trend was exacerbated by the initial construction of large, wide pools and then ameliorated in the new design for the restored areas.
- Buildup of sediment over the years, followed by flushing during the continual high water of 2013.
- Possible increases and decreases over the years in nutrient loads reaching the creek from upstream sources (trout farm, plant nursery, residential development).

Crayfish: Numbers of the two species of crayfish in our 2011 and 2014 samples are shown in Table 8. As with all but a few species of fish, both species of crayfish were taken in lower numbers in 2014, but Betty Creek at the Hambidge Center still provides adequate habitat for the watershed endemic Little Tennessee River crayfish (*Cambarus georgiae*) as well as the ubiquitous Appalachian brook crayfish (*Cambarus bartoni*).

Conclusions from species inventory: In our 2012 report we stated that "it is clear that changes which occurred in the fish assemblage of Betty Creek at the Hambidge Center during 2003-2008 are much more significant than those reflecting effects of restoration work during 2010-2011". The same applies to the 2013 work with the exception that the changes made in 2013 appear to have offset local surges in abundance of lampreys, sunfish and warpaint shiners. (See further discussion under Changes within the Intervened Areas.)

The two other most significant changes reflected by species inventory results are an increase in successful reproduction by rainbow and brown trout and the first evidence of reproduction by invasive yellow perch. Both phenomena may be temporary and do not appear to bear any relation to the restoration work.

IBI RESULTS AND DISCUSSION

As in 2011, the 2 restoration reaches (comprised of intervened and non-intervened sections) were treated as discrete IBI samples. Table 9 compares the IBI and individual metric scores among the 3 sample reaches for 2011 and 2014. Fortuitously, the upper restoration reach corresponds to a reach which had been monitored on 3 occasions prior to the beginning of the restoration project in 2010. Table 10 shows changes in the IBI and individual metric scores in that reach for 5 samples during 1996-2014, which can aid in separating effects of the restoration work from changes corresponding to longer term trends in upper Betty Creek.

Before discussing the 2014 data from the Hambidge Center reach of Betty Creek and comparing it with data from previous years, we should re-emphasize that, problems identified by Golder and Associates leading to the restoration project notwithstanding, since the inception of the Upper Little Tennessee Watershed Biomonitoring Program in 1990, Betty Creek has generally had the highest biotic integrity among 17 tributaries to the Little Tennessee River with watershed areas > 4 mi^2. During 1990-2014, apart from the 6 IBI samples now completed on the Hambidge Center property, we have carried out 27 IBI's at 8 sites along Betty Creek from US 441 in Dillard (0.6 mi. above the mouth of Betty Creek) to a point above the mouth of Barkers Creek where watershed area is 5.5 mi^2. On 21 occasions, encompassing all 8 sites, a bioclass rating of Good was achieved. The exceptions were due to localized problems which have been resolved. This includes a 2013 sample at the uppermost site, above Barkers Creek (IBI 51.0) and a 2014 sample at the lowermost site in Dillard (IBI 54.9).

This needs to be understood in terms of the goals and evaluation of the restoration process. It would be unrealistic to expect that restoration over a limited length of stream would result in a higher IBI over a greater length. Rather the question which should be asked is whether restoration has succeeded in repairing localized problems which, if left unchecked, can spread and contribute to loss of biotic integrity over a longer reach. We will return to this point in the discussion of changes in the intervened areas, which follows this section.

The change which is most immediately apparent from examination of Table 9 is that IBI improved at 2 of the 3 sites, while remaining the same for the reference reach. In interpreting the results it needs to be kept in mind that a difference of 2.7 points (the difference between low, medium or high scores for a single metric) between 2 IBI's should not be treated as significant without supporting evidence. For example, based on the IBI, there are no grounds for saying that the condition of the 2 restoration reaches in 2014 (IBI 52.2) is "better" than that of the reference reach (49.5).

Bearing these limitations in mind, there was significant improvement in both of the restoration reaches, which went from 44.1 (Fair) and 46.8 (Good) in 2011 to 52.2 (Good) at both sites in 2011. In our opinion:

- These changes reflect improvement of conditions in the intervened areas (See discussion of individual metrics and the discussion of the intervened areas in a following section.) over the period 2011-2014.
- Absent modification of the restoration in 2013, there still might have been improvement, since any instream intervention will inevitably have negative effects in the short run. However, in our opinion, much of the improvement is due to the modifications which were made. Unfortunately, there is no way to tease out these differences through biomonitoring. If we are right, assuming the intervened areas stabilize and the condition of the riparian vegetative buffer improves, we should expect further modest improvement in the years to come.
- Measured improvement in biotic integrity may also reflect flushing of accumulated sediment during the unusually high sustained flow conditions of 2013.

Following are discussions of the individual IBI metrics in the context of the 3 sites, grouped according to perceived trend categories:

Metrics with positive change:

The most dramatic improvements during 2011-2014 were in Metrics 7 (% of individuals as omnivores and herbivores) and 11 (% of individuals as darters and sculpins) where all 3 reaches scored higher in 2014. As we will show in a following section, this directly related to improvements in the intervened areas. However, it also likely reflects natural flushing of sediments. The same probably applies to Metric 12 (% of individuals with diseases, parasites and anomalies). Extensive shallow areas with silty substrates conduce to the spread of fish parasites.

Metric 6 (% of individuals as tolerant species) is also of interest in this connection, even though the score for this metric has been universally high in Betty Creek. Only under conditions of severe pollution would we expect less than the high score for this metric in a moderately high gradient, rocky stream like Betty Creek. However, we note that the proportion of tolerants dropped between 2011 and 2014 at all sites. Given that the 3 tolerant species reported from the Hambidge Center property (creek chub, redbreast sunfish and green sunfish) are largely restricted to shallow, mud bottom areas, reduction in their numbers is to be expected.

Metrics with no significant change:

The most interesting metric in this category is Metric 1 (no. of native species). Superficial examination of the observed values for this metric appear to show a decline across all 3 sample reaches. However, all observed values exceed the threshold (10 species) for receiving the high score. Additional species sometimes found may be strays (olive darter), "holdover" individuals of migratory species which "should" be present in spring or fall but not in the summer (whitetail shiner and redhorses), or pond escapees (bluegill, largemouth bass). The only species of some concern in this context are the typically rare fatlips minnow (found at only 1 of the 3 sites in 2014) and the Tuckasegee darter. (See following discussion of darters.)

Metric 7, Catch per Unit Effort: Above the threshold to receive the high score (18 fish/300 sq. ft. standard sample) higher observed values should not be equated with better conditions, but may indicate excess fertility of anthropogenic origin, a factor we have not yet been able to accommodate in the IBI metrics. The consistently lower score for this metric in the reference reach appears to be due to the necessity to include a long and atypically deep pool (>5 ft. vs. a maximum of <3.5 ft. elsewhere). Much of

the area of the pool is both unproductive and difficult to sample properly. If this pool is excluded, catch per unit effort approaches the threshold value of 18 for 2014 and exceeds it for 2011.

Metric 5 (no. of intolerant species) has always received the high score here and elsewhere on Betty Creek, with all 3 intolerants (smoky dace, rock bass and gilt darter) present, albeit in fluctuating numbers.

Metrics with negative change:

Consistently low scores for Metric 8 (% of individuals as specialized insectivores) on a high quality stream like Betty Creek are not altogether surprising. We typically report low scores for this metric throughout the upper Little Tennessee watershed, even on our best streams. We take this to be a reflection of accumulation of sediments in the substrate, particularly in riffle areas, which are well in excess of natural. This reflects the long history of human occupancy, with agricultural and infrastructure development concentrated in the stream valleys. It is unrealistic to expect even a high quality stream like Betty Creek to compete with, for example, streams deep in the Great Smoky Mountains National Park in this regard, and sedimentation directly impacts the stream's ability to produce quantities of small insects as forage for fish.

What is surprising is that observed values for Metric 8 dropped for all 3 sample reaches between 2011 and 2014. We suggest 2 possible, partial explanations:

- The exaggeratedly wide pools created in the first restoration attempt created ideal habitat for the warpaint shiner, a specialized insectivore which prefers this habitat. While if the entire riparian area of Betty Creek at and above the Hambidge Center were deforested, we would expect an across-the board decline in specialized insectivores, including warpaint shiner, riparian vegetation is less important to warpaint shiners than to other specialized insectivores. Large, wide pools provide ideal feeding stations for this species, while the forested riparian zone above and below the pools enhances numbers of both aquatic and terrestrial insects available as food. Warpaint shiners were relatively less abundant throughout in 2014.
- Mottled sculpins are not considered specialized insectivores, but do compete with specialized insectivores for much of their diet, and also compete for space with benthic specialized insectivores (darters, longnose dace, fatlips minnow). An early response to reduced sediment may be a population explosion of sculpins (evident from Metric 11, particularly in the restoration reaches) which swamps the specialized insectivore data.

We would normally expect 3 darter species, corresponding to the high score for Metric 2 (no. of darter species) in Betty Creek at the Hambidge Center. Suboptimal darter diversity was reported for the reference reach (2 species) and the upper restoration reach (1 species). Considering that all 3 species were found at some point on the Hambidge Center property in both years and that the Greenfin darter is still in the process of reestablishing a population in Betty Creek, we are not inclined to put full faith in results for Metric 2. Nevertheless, we are concerned with what appears to be an overall decline in abundance of the always rare Tuckasegee darter.

Summary – 2011 vs. 2014:

While not strictly legitimate, it may be instructive to calculate a total IBI, combining all 3 sites, for the years 2011 and 2014. This eliminates what may be real inter-sector differences in the darter species count (but could also be the result of sampling error) giving a uniformly high score for Metric 2. When this is done, only 2 metrics receive different scores for the 2 years:

- The observed value for Metric 11 (% individuals as darters and sculpins) increases from 56.1, corresponding to the medium score, to 75.8%, (high score).
- The difference for Metric 7 (% individuals as omnivores and herbivores) is even more striking – from 20.9% (low score) to 9.5% (high score).

The result of these 2 changes, combined with the other metrics is to raise the combined IBI from 46.8 (between Fair and Good) to 54.9 at the high end of the Good range. This result reinforces our conclusion that biotic integrity of Betty Creek at the Hambidge Center improved between 2011 and 2014, for reasons at least partially attributable to improvements in the restoration design.

Table 10 expands a table presented in our 2012 report placing the 2014 data for the upper restoration reach in a longer term context. Only 3 of the 9 metrics merit further comment in this context:

The improvement in Metric 2 (no. of darter species) between 2008 and 2011 reflects the ongoing reestablishment of the greenfin darter in the Georgia waters of the Little Tennessee watershed, beginning in 1996, but not extending to the Hambidge Center property until 2011. Its absence from the upper restoration reach in 2014 is doubtful, considering that it was found at both the lower restoration and the reference site. It is to be hoped that the absence of the Tuckasegee darter from both the upper restoration and reference sites in 2014 is a temporary anomaly or due to sampling error.

Results for both Metrics 7 (% individuals as omnivores and herbivores) and 11 (% individuals as darters and sculpins) show a decline during 1996-2008, followed by improvement during 2008-2014, with return to values very similar to those in the 1996 sample. It is beyond the scope of this report to speculate on what all of the factors influencing these changes may have been, but it is worth noting that both of these metrics respond to differences in the sediment content of the substrate. Minor point source pollution from since abated upstream sources may also have played a role in the changes observed during 1996-2008. It appears that improvements due to changes in the restoration design are overlaid on a larger trend.

CHANGES WITHIN THE INTERVENED AREAS

Any discussion of the areas where instream work was carried out as part of a restoration process must begin with a discussion of pre-restoration condition. We did not anticipate the present process, so unfortunately no detailed information is available on fish habitat or use by fish of these specific areas, but it is probable that:

1. Since these areas were fully exposed to the sun following disappearance of tall riparian vegetation, the central stoneroller was the second most abundant species (after the ubiquitous mottled sculpin) and
2. Fish which require pool and deep run habitat (shiners and trout) were scarce or absent. It was clear that, absent some sort of restorative effort, these areas comprised bad situations which were going to not only get worse, but potentially expand up and down the stream.

That said, it must also be acknowledged that any alteration of the bed and banks of a stream is disruptive in the short run, and will result in short-term flushes of sediment which can be detrimental to downstream environments. The fact that both restoration reaches had lower IBI's (44.1 and 46.8) than the reference reach (49.5) in 2011 may be at least partially attributed to major localized disturbance during instream work in 2010.

However, it is also the case that the form of the restructured pools as they existed in 2011 contributed to lowering values for several of the IBI metrics. As of 2011, the new pools were excessively wide, lacking in internal habitat features and had large shallow areas along the shoreline which

accumulated sediments and probably had elevated water temperatures at times. The reconfigured structures, as we found them in 2014, have corrected most of these problems and, with the exception of the element of riparian shade, which will require more time, resemble the natural channel condition of Betty Creek in terms of width, depth, flow rate and habitat features.

These changes are reflected in fish occupancy of the restored areas. Table 11 shows the actual and proportional abundance of individual fish species and groups in the combined intervened areas in 2011 and 2014. While it is not appropriate to attempt to calculate an IBI based on the intervened areas only, it is legitimate to talk about individual metrics as indicators. Table 12 shows 4 selected IBI metrics as applied to the intervened areas.

Species proportions:

Table 10 makes clear that the greatest beneficiary of the reconfiguration of the intervened areas was the mottled sculpin. In 2011, abundance of this dominant species in the intervened areas was less than half that for all other areas. While this scarcely illustrates accomplishment of an urgent restoration goal, it does confirm the return of normal Betty Creek substrate conditions with dominance by cobble size material. Unfortunately, the abundance of sculpins tends to "swamp" the data, making interpretation of other species trends more difficult.

The other clear beneficiaries of the changes made in 2013 were the trouts (here combined with rock bass as "top carnivores"). The swifter flowing, cobble-dominated habitat in the reconfigured pools is much more suitable for trout than pools with large areas of fine substrate. In addition, sculpins are an important prey species for adult trout, particularly brown trout. Of a total 11 adult trout taken in the 2 restoration reaches in 2014, 5 were taken from the intervened areas.

The other easily interpreted changes have to do with the first group of fishes (omnivores and tolerants) in Table 11. All of these species except central stoneroller enjoy a competitive advantage when swift flow over rocky substrates is replaced by slower flow over sand and silt. This is particularly the case for mountain brook lampreys, which spend their larval stage buried in soft sediments and for the 3 tolerant species found at the Hambidge Center (creek chub, redbreast sunfish and green sunfish) which under normal conditions in southern Appalachian streams maintain very small populations concentrated in small muddy pockets. Under the conditions which prevailed in the intervened areas in 2011, these species were concentrated on the broad expanses of shallow, silt and sand bottom on the edges of the newly constructed pools. The return to normal proportions of these species is an indicator of the success of the modifications made in 2013 toward restoring a more natural fish assemblage in Betty Creek.

Central stonerollers were presumably concentrated in the intervened areas in 2011 not so much as a consequence of the restoration work as due to the absence of shade in these areas, permitting the development of algal pastures. Since stonerollers also depend on stable, unsedimented hard substrate, they might have been expected to increase in local abundance after 2013. That they did not is a positive change, but not necessarily attributable to the modifications to the restoration design.

The situation is much less clear with respect to insectivores, both column dwellers and benthic species. To our surprise all species and categories of insectivores (with the non-significant exception of the two benthic minnows, fatlips minnow and longnose dace) declined in both total and proportional abundance in the intervened areas between 2011 and 2014. In the case of the single most abundant specialized insectivore, the warpaint shiner, this may be explicable in terms of the reduced expanse of pool habitat, but all of the other insectivorous species (with the possible exception of the mirror shiner which tends to school over sandy substrates) should have benefitted from stronger flow and a higher proportion of hard substrate. The only plausible explanation is that the mottled sculpin, by virtue of its very large population in the surrounding areas, got a head start and was able to dominate the newly available habitat in the short run. However, this interpretation is weakened by the fact that numbers of

column-dwelling species, which at least theoretically compete less directly with sculpins than benthic insectivores, declined more sharply during 2011-2014.

IBI metrics:

Of the 9 IBI metrics employed, 5 would be substantially unaffected if data from the intervened areas were omitted for either sample year. The other 4 show that the ecological health of the stream can be affected by changes in a relatively small area. In Table 11 note that for 3 of the 4 metrics, for both years the value for the intervened areas is worse than or equal to that for the combined restoration reaches, including the intervened areas. But also note that the discrepancy between the intervened area and total reach values is much less in 2014.

As in the case of proportions of species and species groups, as described above, results for Metric 8 (% individuals as specialized insectivores) appear to be anomalous. For both years, the proportion of specialized insectivores in the sample was higher in the intervened areas than in either of the restoration reaches as a whole, although this difference was much more pronounced in 2011. The only plausible explanation has to do with use of an expanded area of pool habitat by warpaint shiners (especially in 2011).

Metric 11 (% individuals as darters and sculpins) tracks the overall trend toward increasing sculpin abundance beginning after 2008. While restoration may not be the main factor in the improvement for this metric, improved conditions in the intervened areas did contribute to raising the proportion of darters and sculpins over the 65% threshold to receive the high score for 2014 in both restoration reaches.

Dramatic improvement in Metric 7 (% individuals as omnivores and herbivores) is particularly pronounced for the intervened areas and reflects reduction of the abnormally high numbers of tolerant and omnivorous species in the wide, slow moving, soft bottomed pools created in 2010. While factors outside the restoration reaches are certainly involved in improved score for Metric 7 in 2014, the data clearly show the superiority of the new configuration.

Elimination of large expanses of slow moving water over soft substrates also contributed to improvement in Metric 12 (% individuals with diseases, parasites or anomalies). This is principally due to reduction in the incidence of blackspot parasite (*Neascus*) in the intervened areas. By far the most common parasite of stream fishes in our area, this trematode passes one phase of its life in soft sediments, from which it swims upward to attach to passing fish. In 2011 we found a very high incidence of blackspot (4.0%) in the intervened areas, while in 2014, there was no difference between the frequency of blackspot infestation in the intervened areas (0.5%) vs. the rest of the sample reaches.

CONCLUSIONS

It seems advisable here to copy the opening of the "Discussion and Conclusions" section of our previous report:

"We have framed part of the discussion of restoration effects on the Betty Creek fish assemblage in terms of the Index of Biotic Integrity in part because the existence of prior data and the ongoing LTWA (now LTLT) Stream Biomonitoring Program provided a clear opportunity. While IBI sampling should continue to be part of the long term monitoring effort, evaluation of the success of the aquatic component of the restoration should not be based exclusively on IBI monitoring at the Hambidge Center, for two reasons:"

- "There is very limited potential for measurable improvement of biotic integrity in a stream which consistently receives a Good Bioclass Rating."
- "IBI at Betty Creek is clearly subject to effects expressed at the watershed and regional levels, which can mask or override positive or negative effects of onsite anthropogenic changes."

The experience of 2014 serves to underscore these points. Accordingly, we have repeated our approach to discussing the 2011 results by focusing not only on IBI, but also on individual species and species groups plus, this year, effects within the intervened areas of the 2 restoration reaches. Within these categories, we reach the following conclusions:

- Betty Creek at the Hambidge Center continues to maintain a full complement of "expected" fish species; i.e. all of the species we have found in all previous samples on and near the Hambidge Center property were present in 2014. "Missing" species from previous samples represent migrants or strays, which may reappear but should not be determining factors in evaluation of ecological health.
- We are moderately concerned over the apparently diminishing abundance of at least one species, the watershed endemic Tuckasegee darter. However, based on 2014 data, the longnose dace, which as of 2011 was declining, appears to be recovering.
- We are especially pleased at the ongoing recovery in Betty Creek of the regional endemic greenfin darter, which was apparently absent from the Georgia waters of the Little Tennessee watershed from the late 1960's to around 1996.
- The Hambidge Center reach of Betty Creek provides habitat for several other species of conservation concern, including the watershed endemic smoky dace, the Georgia endangered fatlips minnow and the listing candidate Little Tennessee River crayfish.
- Several invasive exotic species are present but not dominant. However, the first evidence, in 2014 of successful reproduction of yellow perch presents a potential threat to the ecological integrity of Betty Creek at the Hambidge Center.
- Our monitoring of fish assemblages in Betty Creek since 1990 suggests that sometime between 2008 and 2014 a long term decline in biotic integrity began to reverse. This is for the most part not due to restoration efforts, but may reflect reduction or elimination of upstream pollution sources and/or flushing of accumulated sediments by continual high flow levels in 2013.
- One obvious change, which would normally be considered an improvement, is the increased potential of the trout fishery resource. In 2014 we noted both more large adults and higher numbers of juvenile trout, indicating more successful reproduction. Within this trend we note that brown trout are becoming more common, nearly achieving parity in abundance with rainbow trout.

- Improvement in ecological health is reflected by a return of IBI index scores to values typical of the late 90's – in the high Good range. It is not realistic to expect further improvement in a populated watershed.
- As is typical throughout the upper Little Tennessee watershed, the major factor limiting the health of the fish assemblage in Betty Creek at the Hambidge Center is the quantity of fine sediment in the substrate. This is reflected especially in the limited numbers of specialized insectivores in the assemblage. Successful completion of the restoration effort and maintenance of ample riparian vegetative buffers at the Hambidge Center can contribute to the resolution of this problem, but it will be a very long term process and must be accompanied by better land management upstream of the Hambidge Center property.
- Until recently, one major local source of sediment and other problems was 2 short reaches of the creek subsequently targeted for restoration by Golder and Associates. Absent this intervention, they would have continued to deteriorate and perhaps expand to the detriment of the entire system.
- The first attempt (in 2010) at restoring these areas failed, in the sense that it created habitat for tolerant and omnivorous species which would be present only in very low numbers under completely natural conditions, while providing a reservoir for fish parasites. Modifications made in 2013 have rectified these problems; assuming good survival and growth of riparian plantings within a few years the intervened areas should not be biologically distinguishable from the rest of the Hambidge Center reach of Betty Creek.
- Reasonable long term goals should be maintenance of IBI in the high Good range, viable populations of all expected native species, and an adequately wide and diverse riparian buffer composed of native vegetation. This is not incompatible with maintenance of a modest recreational trout fishery based on exotic rainbow and brown trout.

Historic biomonitoring results through 2014 continue to show Betty Creek as the healthiest of 17 major tributaries to the Little Tennessee River between Fontana Reservoir and the headwaters above Mountain City, Georgia. Maintenance of this condition is a goal of LTLT and, we assume, the Hambidge Center. Historically, good stewardship on the Hambidge Center property has been a significant factor in maintaining this condition.

This situation can be dramatized by comparing this year's Betty Creek biomonitoring results (Good IBI's of 49.5 and 52.2 at the Hambidge Center and 54.9 in Dillard) with a 2014 result from the Little Tennessee River in the adjacent Wolf Fork valley, less than 4 miles as the crow flies from the Hambidge Center. The Little Tennessee at this point is of similar size (9 mi^2 watershed area vs. 8.26 mi^2 for Betty Creek at the Hambidge Center) and flows parallel to it. However, the Wolf Fork valley has a very different land use history, with intensive and extensive agriculture, channelization of major stretches of the river and its tributaries, industrial sites and in recent years a proliferation of residential development. Our 2014 sample in Wolf Fork produced an IBI of 33.3 (Poor bioclass rating), with over 10% tolerant species, a single stray darter and only 1 trout. We suggest that the existence of parallels such as this can be useful to the Hambidge Center in attempting to develop their educational mission. No further monitoring is scheduled under terms of the contractual arrangement with Golder and Associates until 2018, but we believe further activity involving LTLT, the Hambidge Center and local volunteers, including ongoing comparisons with the Wolf Fork Valley site, would be appropriate.

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Yet again, we must thank Will Griffin of Golder and Associates for taking the initiative to develop the opportunity which this report, its predecessors and others to follow, represent.

Hambidge Center director Jamie Badoud, office manager Deb Sanders and grounds manager Sig Schmid each went the extra mile to insure the success of our efforts.

Thanks to LTLT intern Valery Francis, who participated in every minute of the work here and contributed to keeping long work days upbeat. All the members of the LTLT staff contributed to the success of this effort; special thanks to Stewardship Director Dennis Desmond.

As is typical in the LTLT biomonitoring Program, the work could not have been completed without the enthusiastic participation of community volunteers. In addition to Sig Schmid of the Hambidge Center, this year's volunteers included Sharon Burdette, John Culclasure, Dennis Desmond, Bowman Garrett, Jen Garrett, David Hinson, Laurence Holden, Phil Houston, Ben Laseter, Kelder Monar, David Rothmeir, Rita Rothmeier, Michelle Ruigrok, Ramelle Smith, Sharon Taylor and Ruth West. Special thanks to David Hinson who made the biggest sacrifice.

APPENDIX

Table 1. General characteristics of Bioclass Ratings assigned using the Index of Biotic Integrity (IBI)

Bioclass	IBI Range*	Attributes
EXCELLENT	58-60	Comparable to the best situations without human impacts. Includes all expected species for the particular type and size of stream. All species, including the least tolerant, with full array of sizes and ages. Balanced trophic structure. Low incidence of diseases, parasites and anomalies.
GOOD	48-52	Species richness may be somewhat below expectations, especially due to loss of most intolerant forms. Some species with less than optimal abundance or size distribution. Trophic structure shows some signs of stress.
FAIR	39-44	Fewer intolerant forms. More skewed trophic structure. In some cases older age classes for predators may be rare.
POOR	28-35	Dominance by pollution-tolerant species. Species with specialized habitat requirements scarce. Carnivores scarce. Diseases, parasites and anomalies common.
VERY POOR	12-23	Fish may be scarce or over-abundant (in nutrient-enriched rivers). Tolerant species dominant. Diseases, parasites and anomalies common.

***** When the IBI score falls between the designated ranges, a Bioclass rating is assigned according to the professional judgment of the biologist in charge.

Table 2. Characteristics of the fish sample effort at 3 Index of Biotic Integrity (IBI) monitoring sites on Betty Creek at the Hambidge Center, 2011 and 2014.

Site	Length (ft.)	Mean Width (ft.)	Ratio: length/ width	Sample Area (ft^2)	Electrofisher Time (min.)	Total Fish Number	Total Fish Species
Lower Restoration Reach							
2011	652	22.3	29.3	14,303	118.5	1,505	22
2014	464	19.0	24.4	8,792	76.5	779	21
Upper Restoration Reach							
2011	597	21.0	28.4	13,444	115.8	1,236	22
2014	493	22.3	22.3	10,806	78.3	1,071	16
Reference Reach							
2011	504	23.3	21.6	12,158	115.8	708	23
2014	547	25.8	21.2	14,749	106.7	653	19

Table 3. Annotated list of fish species known to occur in Betty Creek at the Hambidge Center.

Common Name	Scientific Name	Abundance	Trend	Habitat	Comments
Mountain brook lamprey	*Ichthyomyzon greeleyi*	Common	Decreasing	silty shorelines	Temporary dramatic increase in intervened areas reversed.
Rainbow trout	*Oncorhynchus mykiss*	Common	Stable	best pools and runs	EXOTIC
Brown trout	*Salmo trutta*	Rare	Increasing	best pools	EXOTIC
Central stoneroller	*Campostoma anomalum*	Abundant	Increasing	rocky, full sun	
Smoky dace	*Clinostomus* sp.	Common	Increasing	grassy shorelines	Watershed endemic
Whitetail shiner	*Cyprinella galactura*	Rare	????	pools	Fall migrant, not seen in 2014
Warpaint shiner	*Luxilus coccogenis*	Abundant	Increasing	pools	Increase in restoration sites
River chub	*Nocomis micropogon*	Common	Increasing	runs, along shore	Increase in restoration sites
Tennessee shiner	*Notropis leuciodus*	Common	Erratic	deep runs	
Yellowfin shiner	*Notropis lutipinnis*	Rare	Stable	shallow, slow runs	EXOTIC, hybridizes with native cyprinids
Mirror shiner	*Notropis spectrunculus*	Rare	Increasing	runs over sand	
Fatlips minnow	*Phenacobius crassilabrum*	Rare	Increasing	shallow pool heads	Little known species
Longnose dace	*Rhinichthys cataractae*	Rare	Decreasing	fastest riffles	
Creek chub	*Semotilus atromaculatus*	Common	Increasing	silty shorelines	

Table 3. Continued.

Common Name	Scientific Name	Abundance	Trend	Habitat	Comments
White sucker	*Catostomus commersoni*	Rare	????	over soft substrate	Not present in 2011 or 2014 studies
Northern hogsucker	*Hypentelium nigricans*	Common	Increasing	head of pools	
Black redhorse	*Moxostoma duquesni*	Rare	Decreasing	deep pools	Not in restoration sites
Golden redhorse	*Moxostoma erythrurum*	Rare	????	deep pools	Spring migrant
Rock bass	*Ambloplites rupestris*	Rare	Stable	rocky shores	
Redbreast sunfish	*Lepomis auritus*	Rare	Decreasing	pockets along shore	EXOTIC, not seen in 2014
Green sunfish	*Lepomis cyanellus*	Common	Stable	silty shorelines	Temporary dramatic increase in intervened areas reversed.
Bluegill	*Lepomis macrochirus*	Rare	Stable	shallow shorelines	Juveniles, probable pond escapees, not seen in 2014
Spotted bass	*Micropterus punctulatus*	Rare	????	medium depth/flow	EXOTIC, One individual in 2011
Largemouth bass	*Micropetrus salmoides*	Rare	????	shallow shorelines	Juveniles, probable pond escapees, not seen in 2014
Tuckasegee darter	*Etheostoma gutselli*	Rare	Decreasing	riffles w. large rocks	Watershed endemic

Table 3. Continued.

Common Name	Scientific Name	Abundance	Trend	Habitat	Comments
Greenfin darter	*Etheostoma chlorobranchium*	Rare	Increasing	riffles w. large rocks	Regional endemic, becoming reestablished
Yellow perch	*Perca flavescens*	Rare	Increasing	pools	EXOTIC, first evidence of reproduction in 2014
Gilt darter	*Percina evides*	Common	Stable	shallow riffles	
Olive darter	*Percina squamata*	Rare	????	????	Federally listed as Threatened, 1 individual seen in 2011
Mottled sculpin	*Cottus bairdi*	Abundant	Stable	rocky substrates	By far the most dominant fish

Table 4. Some physical characteristics of 3 Index of Biotic Integrity (IBI) monitoring sites on Betty Creek at the Hambidge Center. 2011 and 2014.

Site	Proportion of Habitat types			Intervened Areas			
	% Pool	% Run	% Riffle	Length (ft.)	Area (ft^2)	Riparian Shade (%)	Max depth (ft.)
Lower Restoration reach							
2011	45	15	40	315	7340	55	3.7
2014	51	15	34	295	4975	55	3.0
Upper Restoration reach							
2011	43	20	37	254	6856	45	3.4
2014	43	22	35	253	5194	45	3.1
Reference reach							
2011	33	24	43	0	0	100	>5.0
2014	31	21	45	0	0	100	>5.0

Table 5. Species and numbers of fish collected in IBI samples from 3 sites on Betty Creek at the Hambidge Center, June-July 2014.

Species	Reference Site	Upper Restoration reach			Lower Restoration reach		
		Non-Int.	Intervened	Total	Non-Int.	Intervened	Total
Mountain brook lamprey	**16**		2	**2**	4	7	**11**
Rainbow trout*	**9**	23	8	**31**	4	2	**6**
Brown trout*	**10**	8	6	**14**	4	6	**10**
Central stoneroller	**5**	38	28	**66**	11	37	**48**
Smoky dace	**30**	5	6	**11**	3	20	**23**
Warpaint shiner	**6**	3	46	**49**	10	23	**33**
River chub	**18**	7	14	**21**	6	22	**28**
Tennesee shiner	**1**	10	26	**36**	11	27	**38**
Yellowfin shiner*	**3**		1	**1**	1	2	**3**
Yellowfin shiner x smoky dace	**1**				1		**1**
Yellowfin shiner x Tennessee shiner		1		**1**			
Mirror shiner	**6**	1	6	**7**	5	4	**9**
Fatlips minnow						3	**3**
Longnose dace	**10**	5	7	**12**	5	2	**7**
Creek chub	**3**				4	2	**6**
Northern hogsucker	**8**	4	7	**11**	2	7	**9**

Table 5. Continued.

Species	Reference Site	Upper Restoration reach			Lower Restoration reach		
		Non-Int.	Intervened	Total	Non-Int.	Intervened	Total
Rock bass	**1**	1	2	**3**	3	2	**5**
Green sunfish	**11**		3	**3**		1	**1**
Tuckasegee darter					1		**1**
Greenfin darter	**4**				5	4	**9**
Yellow perch	**13**				5		**5**
Gilt darter	**2**	7		**7**	2	4	**6**
Mottled sculpin	**495**	385	411	**796**	207	321	**528**
TOTAL	**653**	**496**	**574**	**1071**	**292**	**486**	**778**

* non-native species

Table 6. Total length (mm.) of adult trout taken in 3 IBI samples on Betty Creek at the Hambidge Center, 2014

	Total length of adults (mm)		No. juveniles	
	Rainbow trout	Brown trout	Rainbow trout	Brown trout
Reference Site	130		8	10
Upper Restoration Site	315 247 189 141 (1 escaped, not measured)	325 301 224	27	11
Lower Restoration Site	180 125 (1 escaped, not measured)	(1 escaped, not measured)	4	10
TOTAL	**9**	**4**	**39**	**31**

Table 7. Relative abundance of benthic insectivores compared to herbivores at a monitoring site on Betty Creek at the Hambidge Center, 1996-2014

	Proportion of total fish sample				
Group	1996	2003	2008	2011	2014
Sculpin (1 sp.)	75.2	71.5	44.3	52.3	70.6
Darters (4 spp.)	1.7	1.3	1.1	1.5	0.7
Benthic cyprinids (2 spp.)	3.4	4.0	1.5	0.5	0.7
Total benthic insectivores	**80.3**	**76.8**	**46.9**	**54.3**	**72.0**
Benthic herbivore (1 sp.)	1.0	5.9	11.6	10.6	6.2

Table 8. Numbers of 2 species of crayfish from 3 sample sites on Betty Creek at the Hambidge Center, 2011 and 2014.

		Upper Restoration Reach			Lower Restoration Reach		
Species	Reference Reach	Non-intervened	Intervened	Total	Non-intervened	Intervened	Total
2011							
Cambarus bartoni	**45**	30	5	**35**	36	6	**42**
C. georgiae	**5**	6	3	**9**	13	6	**19**
Total	**50**	**36**	**8**	**44**	**49**	**12**	**61**
2014							
C. bartoni	**15**	18	17	**35**	13	11	**24**
C. georgiae	**3**	4	4	**8**	2	7	**9**
Total	**18**	**22**	**21**	**43**	**15**	**18**	**33**

Table 9. Index of Biotic Integrity (IBI) results for 3 reaches of Betty Creek on the Hambidge Center property, 2011 and 2014.

2011

	Reference reach		Upper Restoration reach		Lower Restoration reach	
Metric	Observed Value	Score	Observed Value	Score	Observed Value	Score
No. native species	19	6.7	18	6.7	18	6.7
No. darter species	3	6.7	3	6.7	3	6.7
No. intolerant species	3	6.7	3	6.7	3	6.7
% individuals as tolerant species	6.5	6.7	2.8	6.7	1.3	6.7
% individuals as omnivores & herbivores	13.0	4.0	23.7	1.3	20.1	1.3
% individuals as specialized insectivores	11.9	1.3	18.5	1.3	23.3	4.0
Catch per unit effort	17.5	4.0	27.6	6.7	31.6	6.7
% individuals as darters and sculpins	67.7	6.7	53.9	4.0	52.4	4.0
% individuals w. disease or anomaly	1.7	6.7	2.2	4.0	2.7	4.0
TOTAL SCORE (IBI)		**49.5**		**44.1**		**46.8**
BIOCLASS		**GOOD**		**FAIR**		**GOOD**

Table 9. Continued.

2014

Metric	Reference reach		Upper Restoration reach		Lower Restoration reach	
	Observed Value	Score	Observed Value	Score	Observed Value	Score
No. native species	15	6.7	12	6.7	17	6.7
No. darter species	2	4.0	1	4.0	3	6.7
No. intolerant species	3	6.7	3	6.7	3	6.7
% individuals as tolerant species	2.1	6.7	0.3	6.7	0.9	6.7
% individuals as omnivores & herbivores	7.0	6.7	8.8	6.7	13.2	4.0
% individuals as specialized insectivores	9.0	1.3	11.1	1.3	16.1	1.3
Catch per unit effort	13.3	4.0	29.7	6.7	26.5	6.7
% individuals as darters and sculpins	76.1	6.7	75.0	6.7	74.7	6.7
% individuals w. disease or anomaly	0.5	6.7	0.2	6.7	0.5	6.7
TOTAL SCORE (IBI)		**49.5**		**52.2**		**52.2**
BIOCLASS		**GOOD**		**GOOD**		**GOOD**

Table 10. Index of Biotic Integrity (IBI) results for the upper restoration reach on Betty Creek at the Hambidge Center during 1996-2014.

Metric	1996		2003		2008		2011		2014	
	Observed Value	Score	Observed Value	Score	Observed Value	Score	Observed Value	Score	Observed Value	Score
No. native species	16	6.7	15	6.7	18	6.7	18	6.7	12	6.7
No. darter species	2	4.0	2	4.0	2	4.0	3	6.7	1	4.0
No. intolerant species	3	6.7	3	6.7	3	6.7	3	6.7	3	6.7
% individuals as tolerant species	1.7	6.7	0.7	6.7	2.0	6.7	2.8	6.7	0.3	6.7
% individuals as omnivores & herbivores	6.4	6.7	11.6	4.0	25.2	1.3	23.7	1.3	8.8	6.7
% individuals as specialized insectivores	14.3	1.3	13.5	1.3	23.5	4.0	18.5	1.3	11.1	1.3
Catch per unit effort	25.4	6.7	15.6	4.0	29.7	6.7	27.6	6.7	29.7	6.7
% individuals as darters and sculpins	76.9	6.7	73.0	6.7	45.4	4.0	53.9	4.0	75.0	6.7
% individuals w. disease or anomaly	1.2	6.7	0.5	6.7	1.0	6.7	2.2	4.0	0.2	6.7

Table 10. Continued.

Metric	1996		2003		2008		2011		2014	
	Observed Value	Score	Observed Value	Score	Observed Value	Score	Observed Value	Score	Observed Value	Score
TOTAL SCORE (IBI)		**52.2**		**46.8**		**46.8**		**44.1**		**52.2**
BIOCLASS RATING		**GOOD**		**GOOD**		**GOOD**		**FAIR**		**GOOD**

Table 11. Proportions of fish species and groups of species in intervened areas from Betty Creek restoration project, Hambidge Center, 2011 and 2014.

	2011		2014	
Group	Count	% of Total	Count	% of Total
Omnivores and Tolerants				
Mountain brook lamprey	104	8.3	9	0.8
Central Stoneroller	117	9.3	65	6.1
River chub	135	10.8	36	3.4
Creek chub	14	1.1	2	0.2
Yellowfin shiner & hybrids	23	1.8	5	0.5
Sunfishes (3 spp.)	31	2.5	4	0.4
TOTALS	**424**	**33.9**	**121**	**11.3**
Top Carnivores				
Trouts (2 spp.)	10	0.8	22	2.1
Rock bass	7	0.6	4	0.4
TOTALS	**17**	**1.4**	**26**	**2.4**
Mottled Sculpin	**319**	**31.2**	**732**	**68.3**
Column-Dwelling Insectivores				
Warpaint shiner	181	14.4	69	6.4
Tennessee shiner	92	7.3	53	4.9
Mirror shiner	46	3.7	10	0.9
Smoky dace	42	3.4	26	2.4
TOTALS	**361**	**28.8**	**158**	**14.7**

Table 11. Continued.

Group	2011 Count	2011 % of Total	2014 Count	2014 % of Total
Benthic Insectivores				
Northern hogsucker	35	2.8	14	1.3
Benthic minnows (2 spp.)	10	0.8	12	1.1
Darters (4 spp.)	14	1.1	8	0.7
TOTALS	**59**	**4.7**	**34**	**3.2**
Grand Totals	**1252**	**100.0**	**1071**	**99.9**

Table 12. Selected IBI metric values for intervened areas of the Betty Creek restoration site, Hambidge Center, 2011-2014.

	2011		2014	
Metric	Intervened area	Combined restoration reaches	Intervened area	Combined restoration reaches
7. % of individuals as omnivores & herbivores	31.4	20.9	10.9	9.5
8. % of individuals as specialized insectivores	30.8	19.3	16.6	12.2
11. % of individuals as darters & sculpins	32.1	59.1	69.1	75.8
12. % of individuals with disease, parasites or anomalies	4.0	2.2	0.5	0.5