Aquatic Ecosystems

Information presented in this draft report is considered under development. It may be incomplete and is likely unedited. This may make some sections difficult to follow. An updated version if this report will be posted when it becomes available.

(information taken from NCWAP 2005, and appropriate basinwide plans, unless noted otherwise

The overall richness of North Carolina's aquatic fauna is directly related to the geomorphology of the state, which defines the major drainage divisions and the diversity of habitats found within. Seventeen major river basins are identified in North Carolina (Figure XXX). Five western basins are part of the Interior Basin (IB) and drain to the Mississippi River and the Gulf of Mexico (Hiwassee, Little Tennessee, French Broad, Watauga, and New). Parts of these five river basins are within the Nantahala and Pisgah National Forests. Twelve central and eastern basins are part of the Atlantic Slope (AS) and flow to the Atlantic Ocean. Of these twelve basins, parts of the Savannah, Broad, Catawba, and Yadkin-Pee Dee basins are within the Nantahala and Pisgah National Forests. As described later in this report, the Nantahala and Pisgah National Forests, for the most part, support higher elevation coldwater streams, and relatively little cool- and warmwater resources. The majority of aquatic species diversity occurs in the small amount of cool- and warmwater resources.

Figure XXX. INSERT Small map of river basins, with N/P basin highlighted.

A long history of separation between drainage basins in the eastern United States has culminated in differentiation of their respective faunas. For example, distinct aquatic communities are found on each side of the Eastern Continental Divide (ECD) with relatively few native species in common. Additionally, within each major drainage basin, individual river basins drain broadly diverse terrain and a wide variety of aquatic habitats exist among them. In an assessment of southeastern states, North Carolina ranked third highest in overall diversity of stream-types (Warren et al. 1997).

The southeastern United States supports the highest aquatic species diversity in the entire United States (Burr and Mayden 1992, Taylor *et al*. 1996, Warren *et al*. 2000, Williams *et al*. 1993). Southeastern fishes make up 62% of the United States fauna, and nearly 50% of the North American fish fauna (Burr and Mayden 1992). Molluscan diversity in the region is 'globally unparalleled', with 91% of all United States mussel species found in the southeast (Neves *et al*. 1997). Crayfish diversity and global importance in the region rivals that of mollusks (Taylor *et al.* 1996). Crayfish in the southeast comprise 95% of the total species found in all of North America (Butler 2002a).

In North Carolina, water quality has improved over the last several decades in many waters that were historically polluted primarily by point-source discharges; however, overall habitat

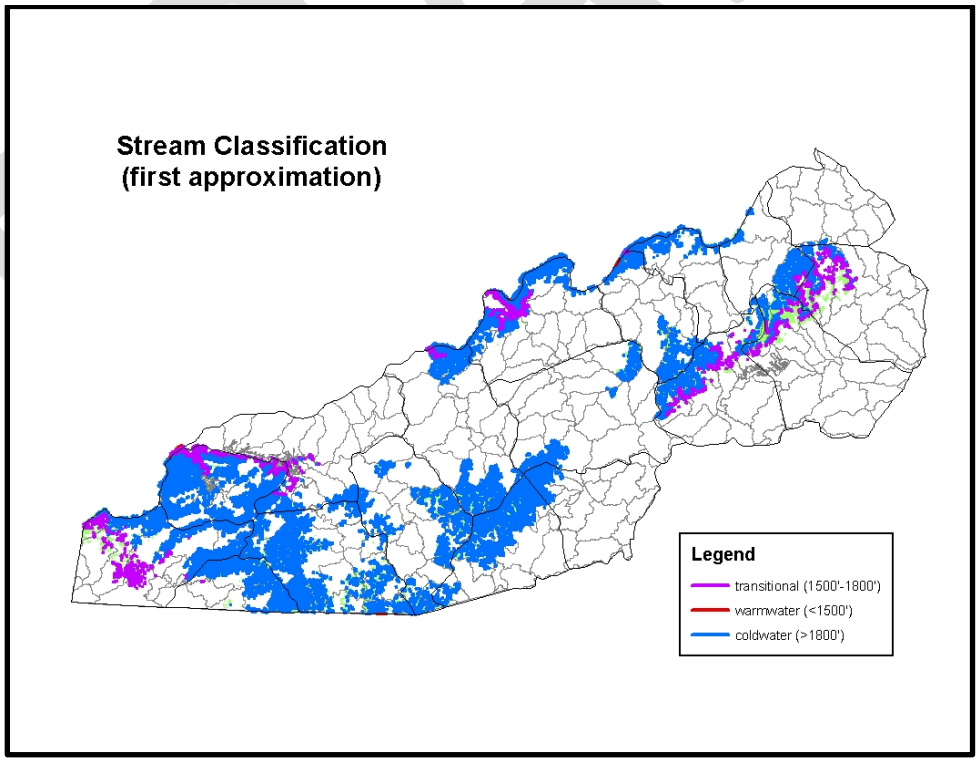
degradation continues to threaten the health of aquatic communities. Increased development and urbanization, poorly managed crop and animal agriculture, and mining impact aquatic systems with point and nonpoint source inputs. Additionally, impoundments on major rivers and tributaries drastically alter the hydrologic regime of many North Carolina waterways and result in habitat fragmentation, blockage of fish migration routes, and physical habitat alterations.

The mountains of the Blue Ridge Physiographic Province (BRPP) dominate the western third of the state, and therefore the Nantahala and Pisgah National Forests. Generally, streams in the BRPP are relatively high gradient, cool, have boulder and cobble or gravel bottoms, and are of low to moderate productivity. Larger streams and rivers historically supported exceptionally diverse warm-water communities. The five river basins of the IB, along with the Savannah, are entirely within the BRPP in North Carolina. Headwaters of the Broad, Catawba, and Yadkin-Pee Dee river basins drain the eastern slopes of the BRPP.

COLDWATER STREAM AQUATIC ECOZONE

Coldwater streams are the most widespread aquatic habitat of the mountain region of North Carolina. There are approximately 15,000 miles of coldwater stream habitat in western North Carolina, with approximately 3,550 of that (25%) flowing through the Nantahala and Pisgah National Forests (Figure XXX).

Figure XXX. *Stream classification on the Nantahala and Pisgah National Forests.*



Most coldwater streams in North Carolina are of low stream order (i.e. 3rd order or less). This includes headwater reaches where perennial streams originate, downslope through several stream confluences to what most people identify as a small river (Figure XXX). Higher order streams may be classified as coldwater if elevation (as a surrogate for water temperature) or groundwater influences dictate.

Figure XXX. *Coldwater stream habitats on the Nantahala and Pisgah National Forests: (a) first order stream and (b) third order stream.*

Insert example photos of 1st and 3rd order streams.

Coldwater, by its very mnemonics, means the water is "cold" most, if not all, of the time. Trout and other species depend on this characteristic for their life history. For example, brook trout cannot exist in habitats where the water temperature exceeds 18°C for extended periods of time (similarly, lethal temperatures for rainbow and brown trout are 25°C and 27°C, respectively) (Schmitt *et al*. 1993, Raleigh *et al*. 1984, Raleigh *et al*. 1986). Because it is impossible to measure and monitor water temperature on every stream across the Nantahala and Pisgah National Forests, elevation is used as a surrogate to aid in defining coldwater ecosystems. Water temperature is directly correlated to elevation (Schmitt *et al*. 1993).

Because of the topography in western North Carolina, most coldwater streams have high gradients. This lends itself to well-defined pool and riffle habitat in stream reaches with higher gradient, and more run habitat in reaches with lower gradient (Figure XXX). This habitat diversity contributes greatly to trout population stability over the long-term (Schmitt *et al*. 1993, Raleigh *et al*. 1984, Raleigh *et al*. 1986).

Figure XXX. *Habitat diversity within coldwater streams: (a) pool, (b) riffle, and (c) run habitats.*

Insert example photos of pool, riffle, and run habitats.

Other geochemical factors correlated with trout, and particularly brook trout, density and population stability are underlying geology and stream pH (Schmitt et al. 1993). These factors are discussed in depth in other parts of this document. Specific relationships with brook trout distribution and abundance with these physical factors should be examined in the revised forest plan process.

Schmitt et al. 1993, Raleigh et al. 1984, Raleigh et al. 1986 all indicate, that besides stream productivity and habitat-limiting factors discussed above, the availability of suitable spawning habitat (i.e. clean, silt-free gravel) limits trout population density in southern Appalachian streams. This is particularly true where brook trout occur with other trout species. Therefore it is critical that spawning habitat and juvenile age classes be monitored in future efforts.

Range-wide and Local Trends

Brook trout (*Salvelinus fontinalis*) are the only trout native to much of the eastern United States. They have inhabited the East's coldwater streams and lakes since the retreat of the continental

glaciers across New York and New England, and they have thrived in the Appalachians for the last several million years. Brook trout survive in only the coldest and cleanest water. In fact, brook trout serve as indicators of the health of the watersheds they inhabit. A decline in brook trout populations can serve as an early warning that the health of an entire system is at risk (Eastern Brook Trout Joint Venture (EBTJV) 2012).

In pre-Colonial times, brook trout were present in nearly every coldwater stream and river in the eastern United States. Sensitive to changes in water quality, wild brook trout began to disappear as early agriculture, timber and textiles economies transformed the eastern landscape by stripping the region's protective forests and filling the streams with sediment and pollution. As streams gained value as highways for log drives, water sources for farming, and prime locations for factories and mills, the resulting loss in brook trout populations mirrored the broader decline in the health of the region's lands and waters. Many of these threats to water quality and wild brook trout persist today, as our population and resource needs increasingly expand. New challenges associated with urbanization place additional stresses on the eastern landscape and remaining brook trout habitat.

Historically, the southern Appalachian Mountains suffered from poor land use practices including large-scale log drives that affected and rearranged stream habitats on a very large scale and poor land management associated with agriculture that increased erosion and opened shaded streams to the sun. As water quality declined and native brook trout disappeared, rainbow trout and brown trout were introduced. As forests returned and aquatic habitat improved, these non-native fish expanded their range and now compete with brook trout for food and space. Most remaining high quality trout habitat is occupied by non-native fish.

Today, the EBTJV identifies the presence of nonnative trout (rainbow and brown trout) and urbanization as the largest threats to native brook trout, followed closely by poor land management and degraded streamside habitat. Furthermore, the EBTJV identifies the Great Smoky Mountains National Park and the Cherokee, Nantahala, and Pisgah National Forests as supporting the highest quality trout habitat remaining in the Southeast. Protection and connection of these small, fragmented brook trout populations to lower elevation rivers will ensure their long-term survival in the face of droughts and floods. Continued protection of forested land, cooperative restoration of streamside areas on private land and selective removal of non-native fish can restore healthy populations of brook trout.

On the Nantahala and Pisgah National Forests 91% (3,460 miles) of the approximately 3,800 miles of perennial streams have been classified as coldwater. Brook trout currently occupy approximately 750 miles of this habitat (Figure XXX). If the assumption that brook trout occupied suitable habitat historically, this represents an almost 80% reduction in range of the species over the long-term, which is emphasized by the EBTJV's estimates of regional range loss (Figure XXX).

Figure XXX. *Current brook trout range on the Nantahala and Pisgah National Forests.*

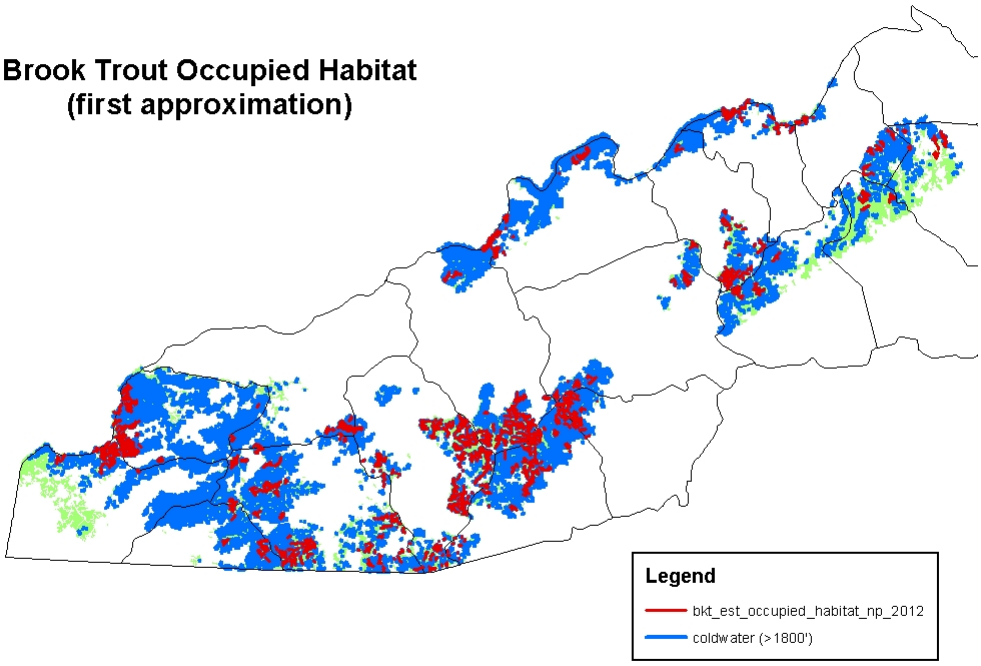
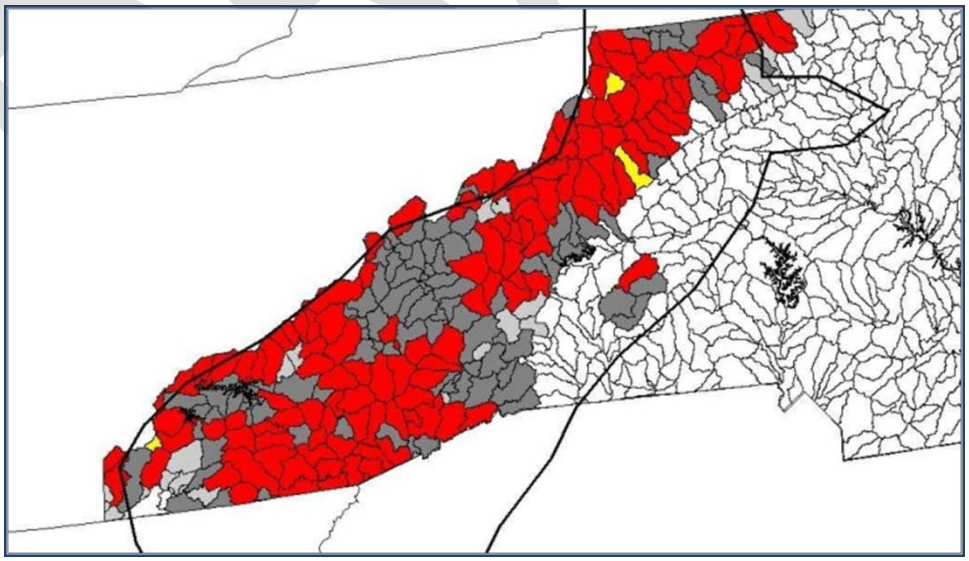


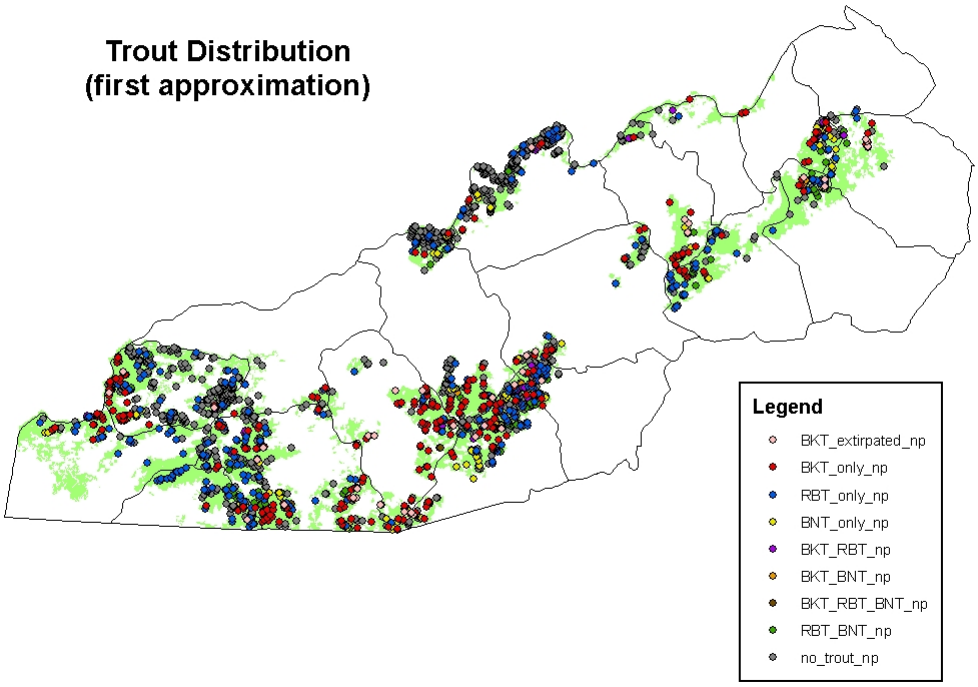
Figure XXX. *Estimated brook trout range loss across the southern Appalachian Mountains. Data courtesy of the Eastern Brook Trout Joint Venture (EBTJV 2012). Red indicates >75% range loss (restoration), yellow indicates 50-75% range loss (enhancement), and green indicates <50% range loss (protection).*



At least for the Nantahala and Pisgah National Forests, much of the brook trout range loss can be attributed to the presence of rainbow or brown trout (Figure XXX). There are a few streams that

support sympatric brook trout and brown or rainbow trout populations. In these areas, inter-specific competition often controls brook trout population dynamics.

Figure XXX. *Current rainbow and brown trout range on the Nantahala and Pisgah National Forests.*



It is important to note that rainbow and brown trout, while not native to the mountains of North Carolina, are important socially and economically. There is a demand for high quality trout fishing in the mountains of North Carolina, and these species fill this niche. Angling as a form of recreation is addressed in other parts of this assessment.

Long-term trout population monitoring was conducted by the North Carolina Wildlife Resources Commission and Forest Service staffs from 1989 until 1996 (Borawa *et al*. 2001), which enabled managers to see local population dynamics. Results of this effort are summarized below. Since 2001, the NCWRC and Forest Service staffs have focused monitoring efforts on the identification of southern strain brook trout populations and distribution of the species.

To date, over 500 populations of brook trout have been sampled from North Carolina (including the Nantahala and Pisgah National Forests), and genetic analysis (via non-lethal tissue samples) conducted to determine strain origin. This is important because northern strains of brook trout were introduced at around the same time brown and rainbow trout were introduced, and have shown to out-compete the native southern strain of brook trout (i.e. “speckled trout”) in some situations. It is the objective of the NCWRC, National Forests in North Carolina, and the Eastern Brook Trout Joint Venture, to restore native brook trout to their appropriate ranges.

Table XXX summarizes results of this long-term effort to identify the range of native brook trout in North Carolina. It is important to note that this genetic work is ongoing, and that beginning in 2012, long-term population monitoring was re-initiated to augment older data and examine trout populations in light of new threats such as acid deposition and global warming.

Table XXX. *Genetic origin of brook trout populations within North Carolina (NCWRC 2012).*

	% northern strain	% southern strain	% mixed strains
Mississippi Basin (n=383)	**6.8**	**43.6**	**49.6**
Cheoah	8.3	66.7	25.0
French Broad	13.0	36.2	50.7
Hiwassee	16.7	66.7	16.7
Little Tennessee	3.2	45.2	51.6
Nantahala	23.5	29.4	47.1
New	2.3	37.2	60.5
Nolichucky	0.0	40.7	59.3
Pigeon	16.7	66.7	16.7
Tuckasegee	2.6	39.5	57.9
Watauga	9.5	52.4	38.1
Atlantic Slope (n=97)	**20.6**	**17.5**	**61.9**
Broad	66.7	33.3	0.0
Catawba	26.9	19.2	53.8
Savannah	0.0	14.8	85.2
Yadkin	26.8	17.1	56.1

Southern Appalachian strain brook trout (SABKT) comprise approximately 40% of all brook trout populations in North Carolina. Within Atlantic Slope drainages, SABKT represent approximately 18% of known brook trout populations. Approximately 44% of brook trout populations within Mississippi Basin drainages are SABKT. These numbers represent the fact that brook trout, although native to the Nantahala and Pisgah National Forests, have been impacted at the genetic level by the introduction of nonnative strains of the species.

At the population level, trout populations exhibit high natural variability. Population stability is largely influenced by the availability of suitable spawning habitat and the recruitment of new age classes. Therefore, this assessment (and potentially future monitoring) will focus on this segment of trout populations. Trout populations across the Nantahala and Pisgah National Forests have been stable to slightly increasing since 1990, although this trend is difficult to see given the natural variability of trout populations (Figure XXX). Trout populations on non-Forest Service lands generally exhibit the same trends (Figure XXX), although several streams have seen measurable declines (Figure XXX).

Figure XXX. *Trout young-of-year (YOY) densities from several streams across the Nantahala and Pisgah National Forests, summarized from Borawa et al. 2001.*

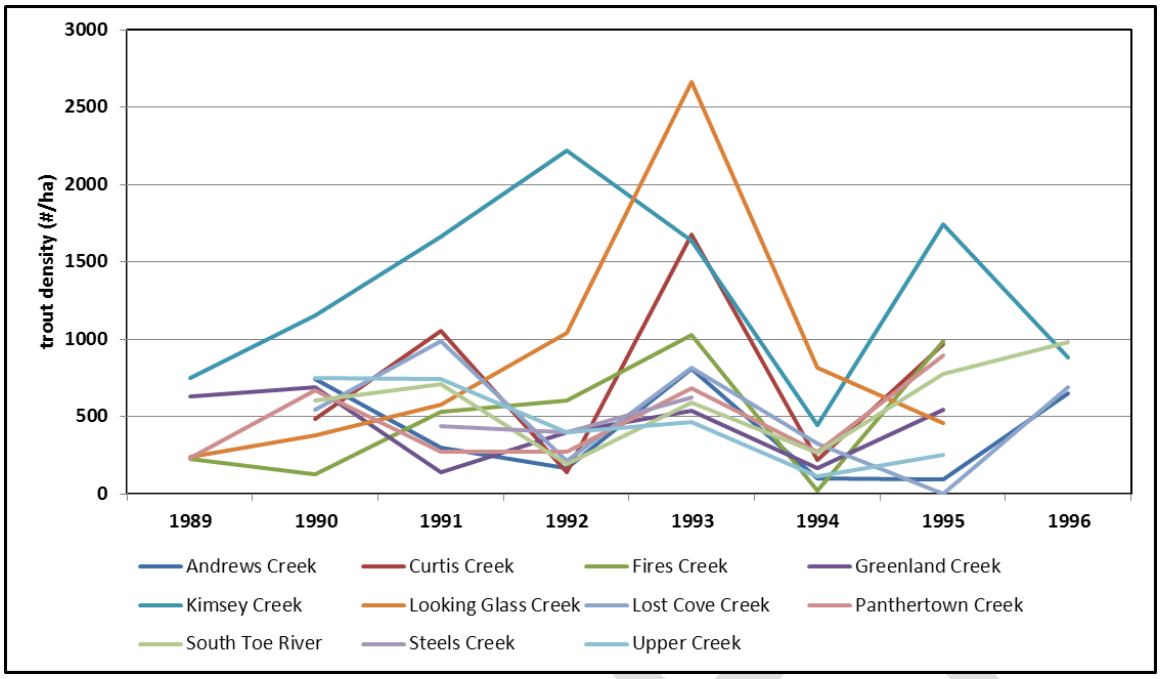


Figure XXX. *Mean trout young-of-year (YOY) densities from streams across the Nantahala and Pisgah National Forests and non-Forest Service lands within western North Carolina, summarized from Borawa et al. 2001.*

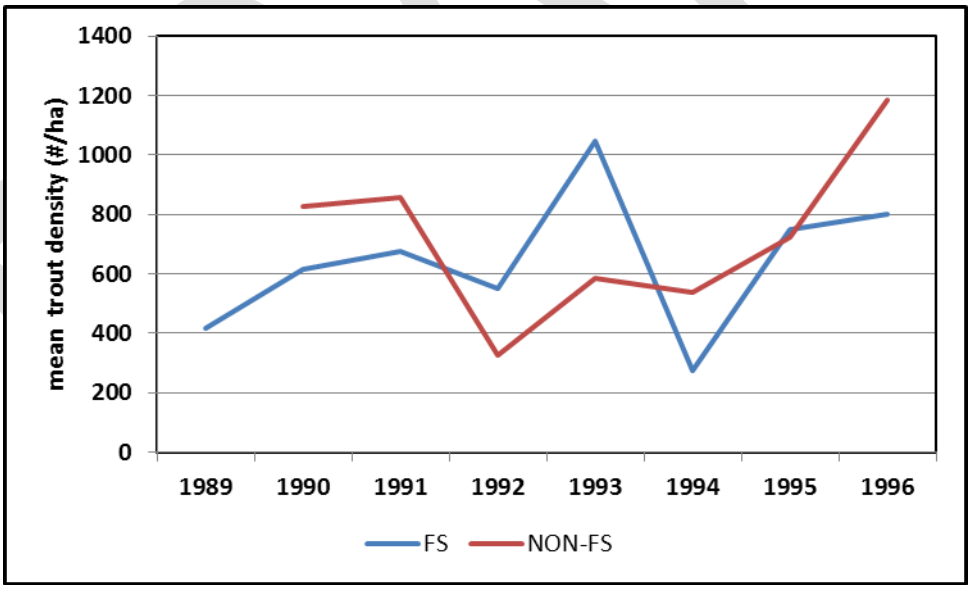
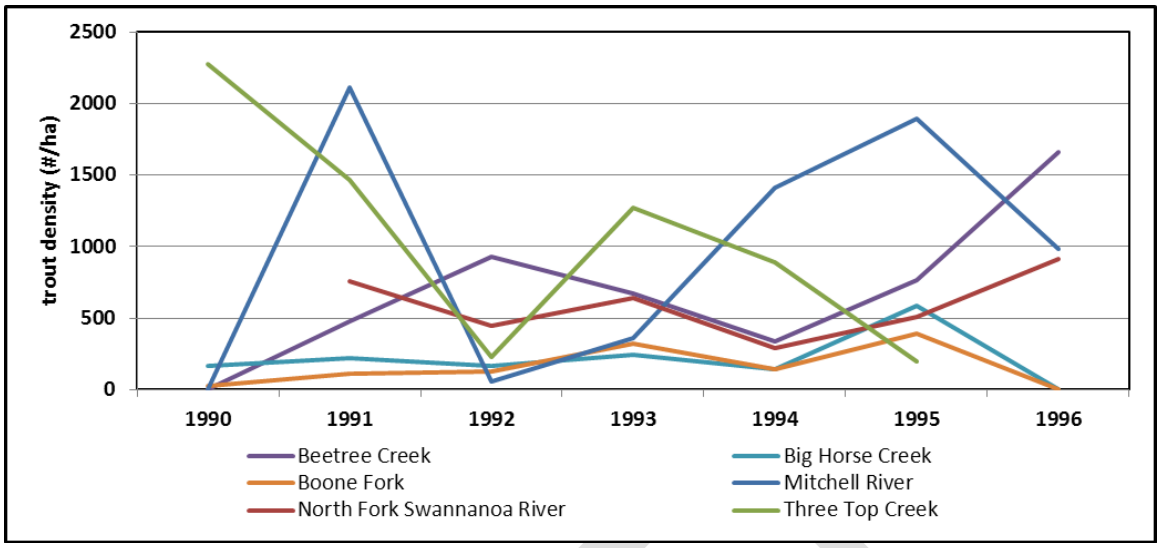


Figure XXX. *Trout young-of-year (YOY) densities from several streams across non-Forest Service lands within western North Carolina, summarized from Borawa et al. 2001.*



Within the monitoring data summarized above for streams across the Nantahala and Pisgah National Forests, allopatric (i.e. brook trout is the only trout species present) and sympatric (i.e. brook trout occur with rainbow and/or brown trout) brook trout populations exhibited different trends. Allopatric brook trout populations exhibit stable to increasing trends across the Nantahala and Pisgah National Forests where no other trout species are present (Figure XXX). Whereas, sympatric brook trout populations exhibit stable to declining trends (Figure XXX). This situation is consistent with the identification of interspecific competition as a threat to brook trout populations by the EBTJV (2012)

Figure XXX. *Allopatric brook trout young-of-year (YOY) densities from several streams across the Nantahala and Pisgah National Forests, summarized from Borawa et al. 2001.*

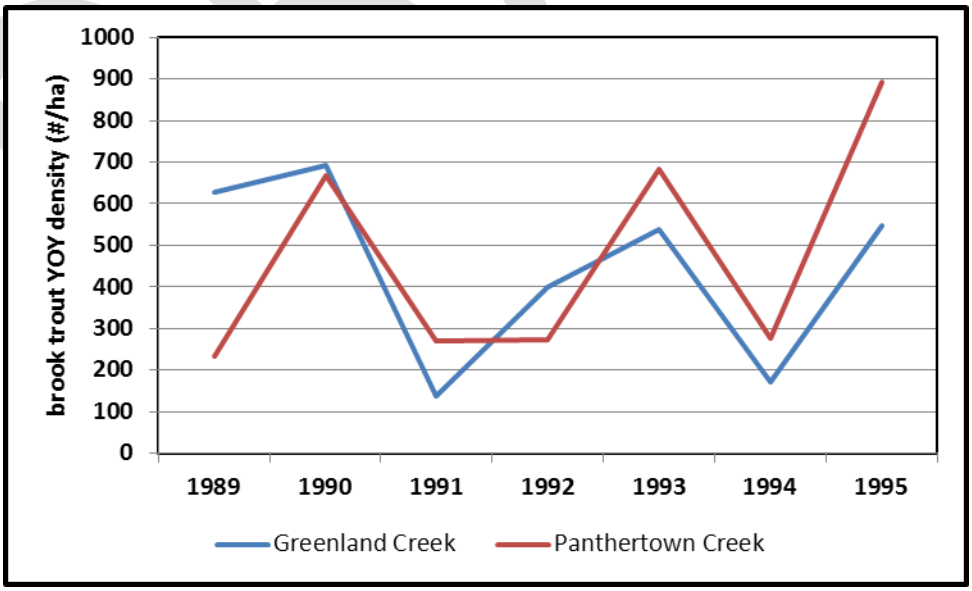
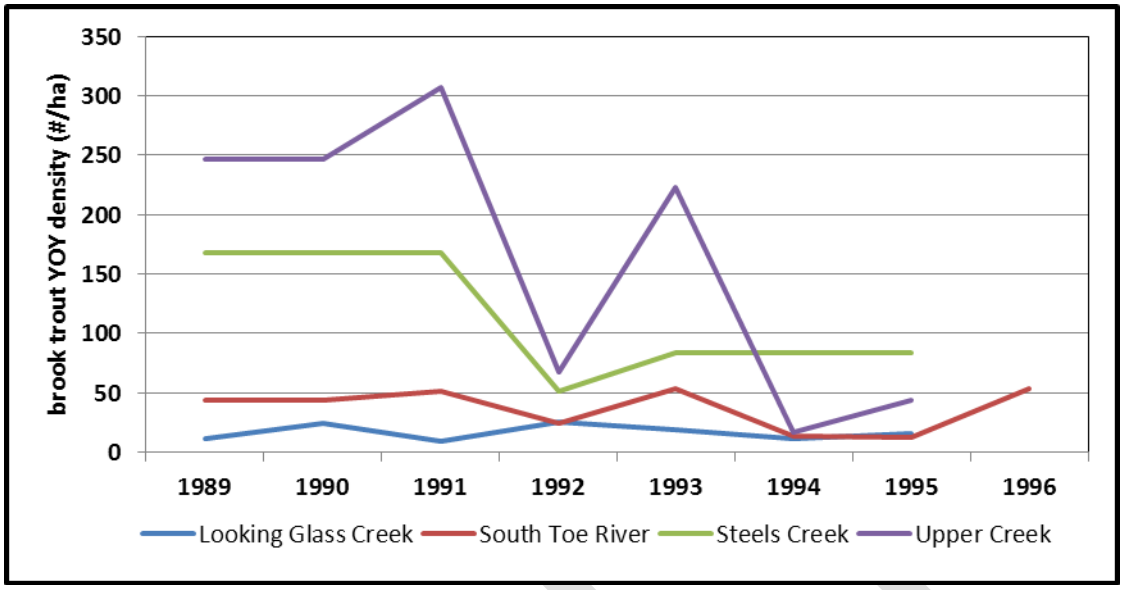


Figure XXX. *Sympatric brook trout young-of-year (YOY) densities from several streams across the Nantahala and Pisgah National Forests, summarized from Borawa et al. 2001.*

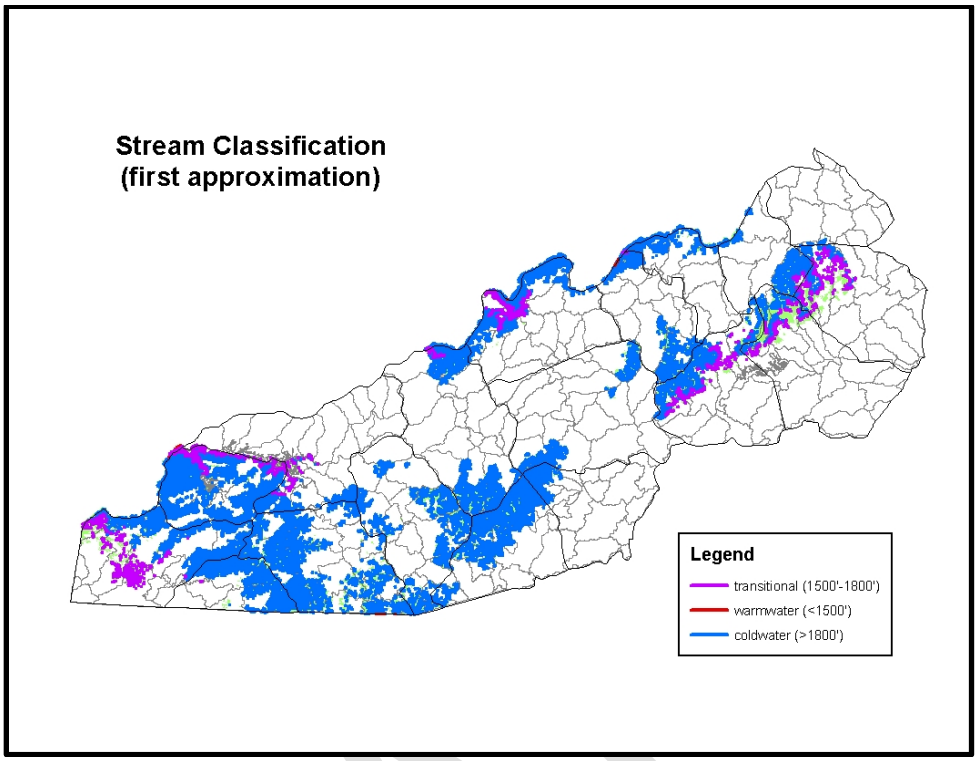


Large-scale stochastic events such as droughts and floods are the primary factors influencing local trout population dynamics (Borawa *et al.* 2001, Schmitt *et al*. 1993). Forest management, particularly the use of roads and trails near streams (including stream crossings), can affect brook trout populations by introducing sediment to stream habitats or blocking upstream movement. However, over the last 20 years, the Forest Service has actively implemented existing Forest Plan riparian standards, restored riparian habitats and brook trout populations, and restored aquatic organism passage at some stream crossings, resulting in the expansion of the range of brook trout on the Nantahala and Pisgah National Forests. It is estimated that the range of brook trout has expanded by approximately 30 miles across the Forests because of these efforts. While not really measurable at Forest scale, these changes are biologically significant at the local scale where restoration and enhancements took place.

COOL- and WARMWATER STREAM AQUATIC ECOZONES

Cool- and warmwater streams are prevalent throughout the mountain region of North Carolina, generally occurring at lower elevations such as large river valleys, and along the Eastern Continental Divide, where the mountain region transitions into the piedmont region. However, because of ownership patterns, these habitats are present, but not in large amounts, on the Nantahala and Pisgah National Forests. There are approximately 246 miles of coolwater (transitional) habitat and 2 miles of warmwater habitat flowing through the Nantahala and Pisgah National Forests (Figure XXX).

Figure XXX. *Stream classification on the Nantahala and Pisgah National Forests.*



Most cool- and warmwater aquatic habitats in North Carolina are of medium and higher stream order (i.e. 4th order or greater), but also includes low-elevation reaches where perennial streams originate (Figure XXX). These habitats support the most diverse aquatic communities on the Nantahala and Pisgah National Forests, and in some cases, represent the most diverse aquatic communities in the southeast and across the United States.

Figure XXX. *Examples of cool- and warmwater streams on the Nantahala and Pisgah National Forests.*

Insert example photos of coolwater and warmwater streams.

Warmwater, by its very mnemonics, means the water is "warm" most, if not all, of the time. Hence, coolwater is the transition, or mixing zone between this and temperature-dependent coldwater habitats (see coldwater streams section of this assessment). The *river continuum concept* (Vannote *et al*. 1980) identifies a watercourse as an open ecosystem that is in constant interaction with the surrounding land, and moving from source to mouth, constantly changing. This metamorphosis is due to the gradual change of physical environmental conditions such as channel width, depth, and gradient, flow characteristics, and air and water temperature, as a system moves from its origin to the ocean.

Because of the topography in western North Carolina, most cool- and warmwater streams have lower gradients, and are wider, which increases solar radiation. As the influence of elevation on water temperature decreases (i.e. the water becomes warmer as streams flow through lower elevations), increased solar radiation also influences water temperature. In western North Carolina, coolwater streams may retain well-defined pool and riffle habitat (Figure XXX),

whereas it is more difficult to discern where one habitat unit stops and another starts in many warmwater habitats on the Nantahala and Pisgah National Forests (Figure XXX).

Other geochemical factors correlated with cool-and warmwater aquatic communities include geology, low pH, environmental contaminants, and physical barriers such as poorly designed stream crossings and dams. These factors are discussed in depth in other parts of this document. Specific relationships between aquatic communities (particularly freshwater mussels and endemic fish) with these physical factors should be examined in the revised forest plan process.

Range-wide and Local Trends

The North Carolina Index of Biotic Integrity (NCIBI) is a modification of the Index of Biotic Integrity (IBI) initially proposed by Karr (1981) and Karr et al. (1986). The IBI method was developed for assessing a stream's biological integrity by examining the structure and health of its fish community. The scores derived from this index are a measure of the ecological health of the waterbody, and may not always directly correlate with water quality. For example, a stream with excellent water quality, but with poor or fair fish habitat, would not be rated excellent with this index. However, in many instances, a stream which rated excellent on the NCIBI should be expected to have excellent water quality.

The IBI (and hence, the NCIBI) incorporates information about species richness and composition, trophic composition, fish abundance, and fish condition. The NCIBI summarizes effects of all classes of factors influencing aquatic faunal communities (water quality, energy source, habitat quality, flow regime, and biotic interactions). While change in a fish community can be caused by many factors, certain aspects of the community are generally more responsive to specific influences. For example: species composition measurements reflect habitat quality effects; information on trophic composition reflects effects of biotic interactions and energy supply; and fish abundance and condition information indicate additional water quality effects. It should be noted, however, that these responses may overlap—for example, a change in fish abundance may be due to decreased energy supply or a decline in habitat quality, and not necessarily a change in water quality. A complete description of the NCIBI method can be found at *http://portal.ncdenr.org*.

The NCIBI is a cumulative assessment of twelve parameters (or metrics) (Table A1). The values provided by each metric are converted into scores on a 1, 3, or 5 scale. A score of 5 represents conditions which would be expected for undisturbed reference streams in the specific river basin or region (the NCIBI takes into consideration physiographic region when defining the 1, 3, or 5 values). A score of 1 indicates that conditions deviate greatly from those expected in undisturbed streams if the region. Each metric is designed to contribute unique information to the overall assessment. The scores for all metrics are then summed to obtain the overall NCIBI score. The NCIBI score (an even number between 12 (extremely disturbed) and 60 (undisturbed)) is then used to determine the ecological integrity of the stream from which the sample was taken.

Table XXX. *NCIBI scores and classification for fish communities within the mountain region of North Carolina. Note that there are two different scales for this region, recognizing differences between Mississippi and Atlantic Slope basins.*

Integrity Class	NCIBI Score (FBR, HIW, LTR, NEW, WAT)	NCIBI Score (BRD, CAT, SAV, YAD)
Excellent	58-60	54-60
Good	48-56	48-52
Good-Fair	40-46	42-46
Fair	34-38	36-40
Poor	</= 32	</= 32

Because it is highly unlikely that any aquatic ecosystem has ever been completely undisturbed, **an NCIBI value of 58 will be used as the baseline (or historical reference) for the analysis of trends in fish community structure** within the French Broad, Hiwassee, Little Tennessee, New, and Watauga River basins, and **an NCIBI value of 54 will be used as the baseline (or historical reference) for the analysis of trends in fish community structure** within the Broad, Catawba, Savannah, and Yadkin River basins.

There are nineteen long-term NCIBI monitoring sites within the eighteen-county area evaluated in this assessment. Twelve of these are on or immediately adjacent to the Nantahala and Pisgah National Forests, and six of these have data consistent enough to establish trends. Additionally, IBI data collected by the Tennessee Valley Authority from sites within North Carolina (hereafter, TVAIBI) is being summarized for this forest plan revision but is not available yet.

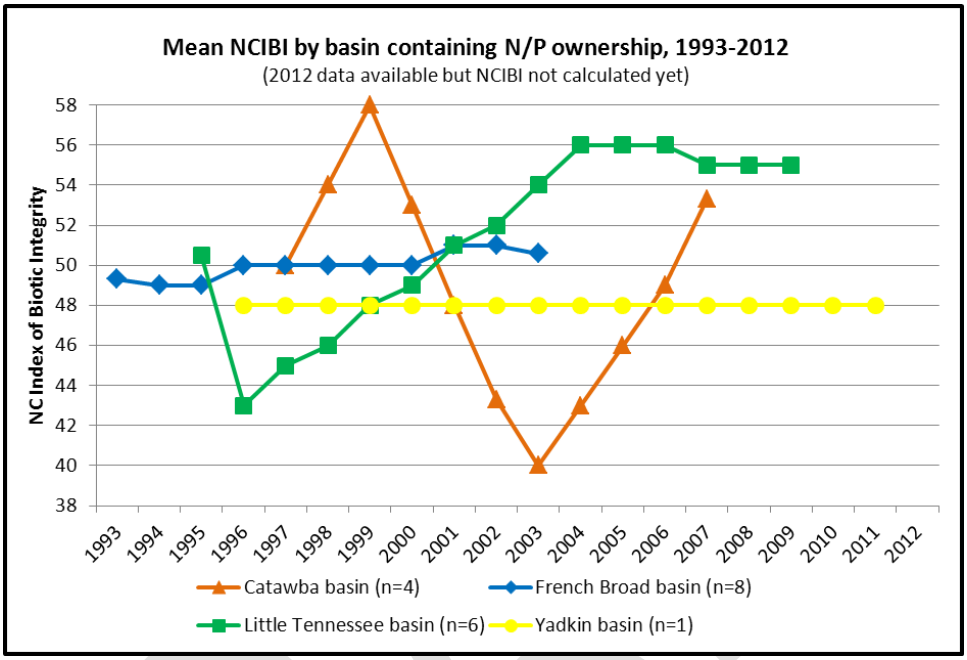
Generally speaking, fish community composition and structure has remained stable to slightly improving within French Broad and Yadkin River Basins (Figure XXX). Fish community composition and structure shows slight improvements within Catawba River Basin, although high variability in NCIBI scores are noted (Figure XXX).

Fish community composition and structure has improved measurably within then Little Tennessee River basin since the mid-1990s (Figure XXX), perhaps due to large-scale grassroots and resource agency efforts in the watershed. Recently, the little Tennessee River basin was named the first native fish conservation area east of the Mississippi River by the National Wildlife Federation, again highlighting the importance of this system and its aquatic health to the planning area.

Use of mean values from all sites within the basin, forest, and relative subbasins explains why odd NCIBI values are displayed. Such values cannot be calculated using valid NCIBI metrics for a site, but can be a result of statistical analysis over one or more sites.) This does not relieve site-specific changes in fish community composition as a result of land use changes or land management (i.e. there are individual streams rating fair or lower in several parts of the basin), but rather reflects the overall health of the landscape. Fish community structure and health

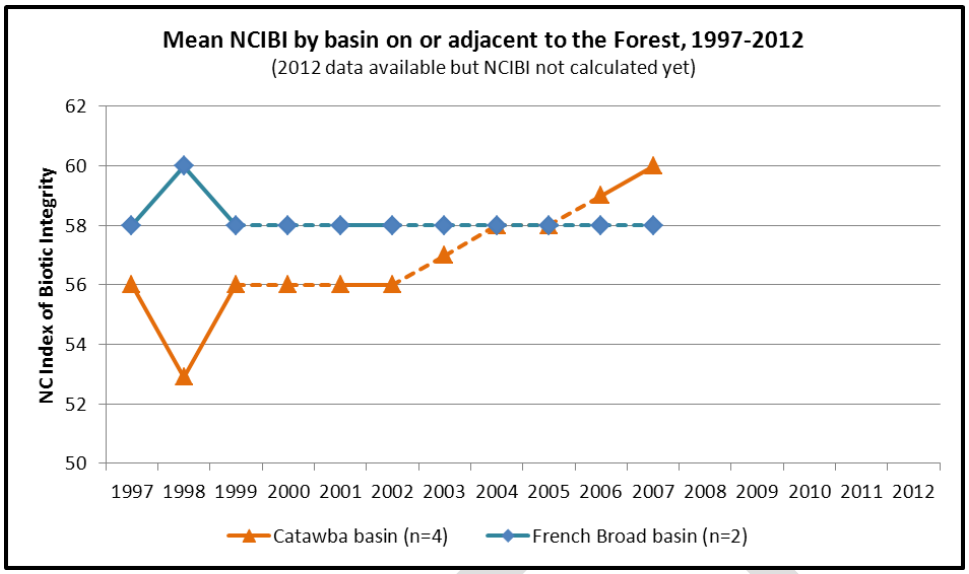
across the Forest does not differ significantly from established "historical" conditions, while values across the basin are slightly lower, but not trending towards loss of structure or function.

Figure XXX. *Mean NCIBI values from streams within river basins containing the Nantahala and Pisgah National Forests.*



A closer look at NCIBI values from the Nantahala and Pisgah National Forests reveals that fish community health is stable within the French Broad river basin, and increasing in the Catawba River basin (Figure XXX). However, very small sample sizes are likely limiting the reliability of these trends.

Figure XXX. *Mean NCIBI values from streams within river basins containing the Nantahala and Pisgah National Forests.*



Maintaining an NCIBI rating of good or better for Forest streams is the desired condition-- high quality, high integrity fish communities across the Nantahala and Pisgah National Forests will ensure the continued existence of stable warmwater fish communities. However, due largely to the zoogeography of native fish, maintenance of healthy, stable fish communities across the Forests will not ultimately guarantee the continued existence of all fish species.

Overall, stream community and health and function has been, and remains, good across the Nantahala and Pisgah National Forest. Across the Forests, only one site within the Catawba River basin during one year of this monitoring (1998) received a NCIBI score lower than the historical reference.

Cool- and warmwater streams support a diversity of aquatic species, including many nongame fish, crayfish, and freshwater mussels. The NCIBI addresses this diversity; however, many of these species are rare or of conservation concern. From this perspective, these species are discussed in other parts of this assessment (reference Federally-Listed Species and Species of Conservation Concern).

REFERENCES (INCOMPLETE IN THIS DRAFT)

NCIBI protocol

Basin plans: FBR, LTN, YAD, CAT, HIW

NCWAP

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