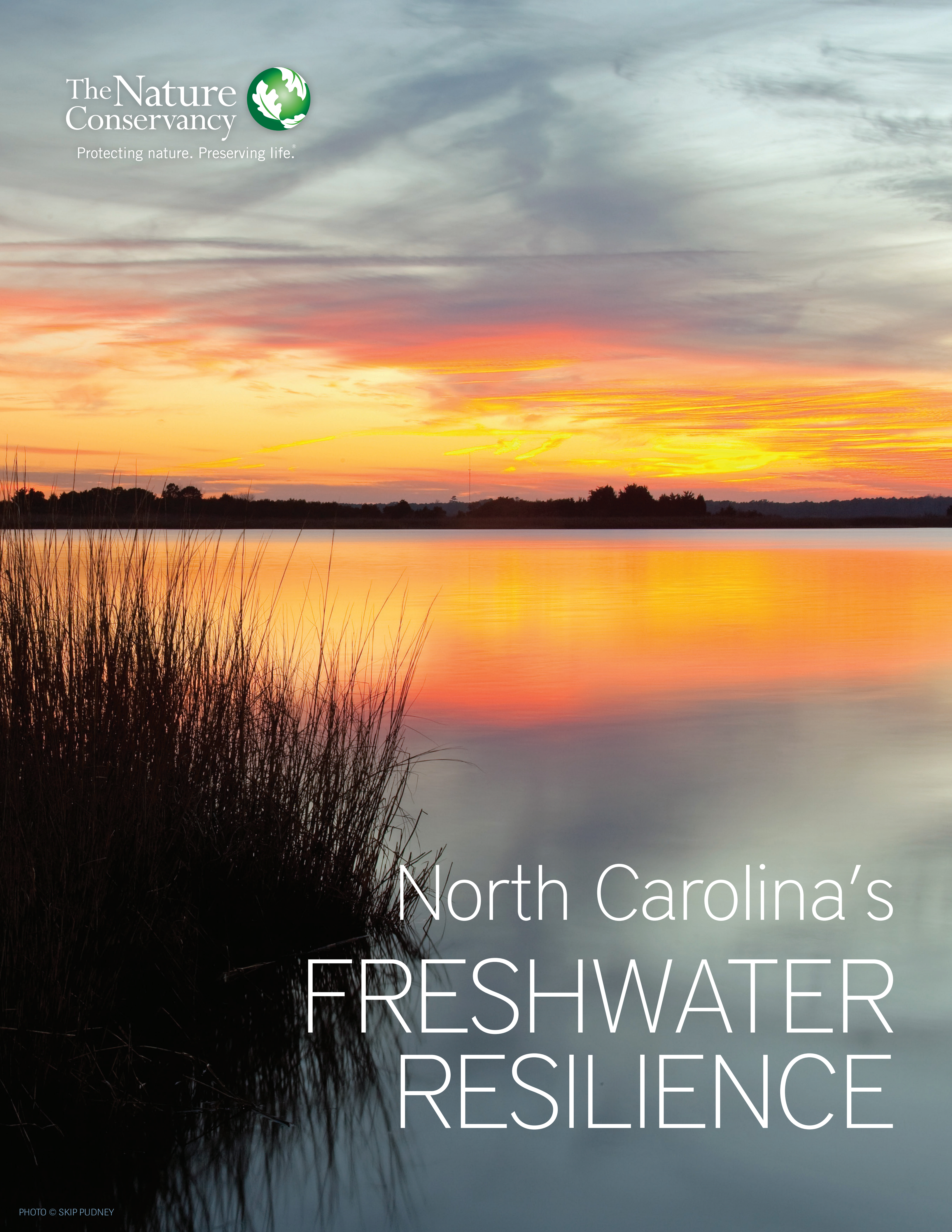

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North Carolina's FRESHWATER RESILIENCE

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North Carolina's Freshwater Resilience

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Abstract

Resilient stream and river systems are those that have the greatest potential to continue to support biodiversity into the future despite, potentially severe and often unpredictable, impacts from climate change. Resilient rivers and streams will be able to retain essential processes because of the existence of particular elements, for example connectivity, that make them more able to adapt to change. Based on various scientific studies and work done by The Nature Conservancy (TNC) in other regions of the US, we conducted a freshwater resilience analysis for the rivers and streams of North Carolina (NC) that classifies these waterways by their degree of resilience or vulnerability. We evaluated resilience based on 12 characteristics. Six of these characteristics were physical properties of the river or stream: network complexity, length of connected network, number of gradient classes, number of temperature classes, elevation range, and baseflow index. Six of them were condition characteristics: impervious surface, floodplain naturalness, adjusted percent cropland, cumulative dam storage, cumulative percent waterbody area, and cumulative water use. We then stratified the state of NC by three ecoregions: Mountains, Piedmont, and Coastal Plain and compared the results of the resilience metrics for the rivers and streams within each ecoregion (i.e. Mountain rivers were compared against each other, Piedmont against each other, etc.) to determine a representative set of the most resilient river and stream networks across the state. Finally, we overlaid streams and rivers identified previously as priorities for biodiversity conservation with our resilience maps to determine where these prioritizations intersect. TNC NC will use the results of the resilience analysis to identify high priority places to focus their freshwater conservation strategies as well as to engage local partners in landscape-scale freshwater conservation efforts.

Introduction

Ecosystem resilience is the ability of an ecosystem to retain essential processes and structure and support biological diversity in the face of disturbances like climate change (definition modified from Gunderson 2000). As the pace of environmental change accelerates due to climate and land use changes associated with a growing human population and rising resource use, identifying areas that are likely to be highly resilient to this change will be increasingly important. Although the precise species composition in a given area will undoubtedly change in response to environmental changes, resilient systems will continue to sustain high levels of biodiversity and ecosystem function, and it is these areas that hold the most promise for conservation in the coming decades.

We developed a project to determine the resilience of North Carolina (NC) rivers and streams based on an analysis completed in the Northeastern US led by TNC's Eastern Division (see Anderson et al. 2013). Recent evidence (Rieman & Isaak 2010, Palmer et al. 2009) suggests that the resilience of freshwater systems can largely be characterized by six elements: linear and lateral connectivity, water quality as shaped by surrounding land use/cover, instream flow regime, access to groundwater, and the diversity of geophysical settings in the area. We used these general characteristics to select and quantify metrics appropriate for NC stream and river systems. We quantified these factors for 1,097 functionally connected stream networks in NC which covered approximately 70% of all stream miles in the state, as mapped by the National Hydrography Dataset Plus version 1 (NHDPlus v1; USEPA & USGS 2006), to develop a comprehensive assessment of resilience across the state's freshwater systems. In cases where data was lacking or incomplete we used proxies and substitutions to assess stream network resilience. Specific details are described in the methodological overview below.

This project was led by the NC chapter of TNC but could not have been completed without the invaluable effort of the Eastern Division Conservation Science team. Additionally, the input from various NC freshwater experts was invaluable for quality control of the results. The results of this analysis will be used to help TNC NC build a freshwater program and further advance freshwater conservation strategies across the state.

Goal/Purpose

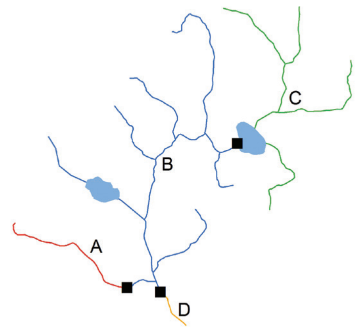
The NC chapter of The Nature Conservancy developed a freshwater resilience analysis to identify the most resilient stream networks in NC that will collectively and individually sustain freshwater biodiversity even as the changing climate and land use alters current distribution patterns. We aim to use the analysis to help prioritize locations and potential strategies for our developing freshwater program. This analysis will be used in tandem with other analyses, including a more general freshwater assessment and a freshwater flows analysis, to help with the prioritization. Additionally, this analysis provides TNC NC an opportunity to more effectively engage with partners across the state already working in freshwater.

Methods

Scale and Unit of Analysis

The functionally connected network (FCN) was the unit of analysis for the study. The FCN is defined as the set of streams bounded by fragmenting features (dams) and/or the topmost upstream extent of headwater streams (see Figure 1). The freshwater analysis included all rivers and streams in NC including parts of the rivers and streams that crossed state boundaries if those areas were part of a functionally connected network.

FIGURE 1. Example of four Functionally Connected Stream Networks. Networks A and C are bounded by headwaters and downstream dams, indicated by the black bars. Network B is bounded by headwaters, two upstream dams on tributaries, one downstream dam on the mainstem, and includes one large lake, indicated by the blue ovals. Network D is bound by the downstream base level and one upstream dam. Network B is considerably longer than network A, C, and D.



Dams bounding the FCNs were mapped from five sources: NC dam safety 2012, NC dam safety 2010, the Aquatic Obstruction Inventory, the National Anthropogenic Barrier Dataset (a spatially accurate version of the National Inventory of Dams, 2009), and an estimated dams analysis. In the case of the NC dam safety 2010 and the Aquatic Obstruction Inventory data, the dams had to be visually reconciled (hand snapped) to the correct river and stream segments using Google imagery for reference. We used the NHDPlus version 1 (National Hydrography Dataset Plus 1:100,000) as the basis for the stream networks. In addition to the above dam databases, which are known to underrepresent the true number of dams on the ground, we estimated additional dams using the NHDPlus v1 waterbodies and stream network. As most lakes and ponds in NC are man-made, we assumed that the presence of a lake/pond likely represented an impoundment. We removed known natural waterbodies from the NHDPlus v1 data and then created an estimated dam at the outflow of each flow line and lake/pond where a dam was not already present in the state dam databases.

The FCNs were derived from the state and estimated dam databases and the NHDPlus flowlines using the Barrier Assessment Tool (BAT). To use the NHDPlus river network with the BAT, bifurcations (loops) had to be removed manually. There are known inconsistencies in NHDPlus v1 stream density due to cartographic interpretations of small streams from 1:24,000 USGS quads (Brakebill et al. 2011). To address this difference, all stream reaches with less than one square mile drainage area were removed from the FCNs and not included in the analysis. As mentioned previously, many of the rivers and streams in NC crossed state borders. In order to ensure we had the whole connected network we used NHDPlus version 2 rivers for areas outside of NC, and snapped dams to this version similarly to version 1 (version 2 is constructed so that the bifurcations can be easily removed).

Our approach for creating FCNs in NC required: hand snapping, finding ways to identify missing dams, and making some estimates as to what was likely a dam versus a natural waterbody or obstruction. As such, some caveats to note with our approach include: 1) Despite efforts made to remove known natural lakes and ponds, the remaining NHDPlus v1 lake/pond polygons may not all be impoundments but we assumed they were. 2) Because of how water bodies are represented in NHDPlus v1 there could be cases where a continuous waterbody is represented as two or more separate polygons. In these cases, points would be generated for each distinct polygon which could potentially overestimate the presence of a barrier. 3) While all pertinent NHDPlus v1 waterbody attribute information was joined to the estimated point locations as was the corresponding NHDPlus v1 flowline information, there is no information on the estimated barrier such as type, size, age, etc. 4) The estimated dam locations need to be compared to existing dam databases and reviewed in conjunction with aerial imagery and/or reviewed by individuals with on-the-ground knowledge of a particular area.

In total, there were over 1,814 FCNs in NC. In our analysis we eliminated FCNs that had less than 1.6 km of stream length as this was assumed to be a safe threshold at which there was enough stream length for biodiversity to live and survive. This reduced the number of FCNs used in the analysis to 1,097. Of those, 850 were what we called headwater FCNs which contained only small headwaters and creeks (see Table 1). The remaining 247 were river FCNs which contained at least one small river (drainage area >38.61mi^2).

Geographic Stratification

We used three geographic stratifications to compare and contrast stream networks, providing a sub-regional context for assessing relative resilience among functionally connected stream networks. In general the stratification reflects the boundaries of the Mountains region, Piedmont region, and Coastal plain region of NC. The goal of the stratifications was to be able to compare the resilience of networks that shared similar fish compositions, zoogeographic history, and local physiography so that we were comparing the resilience of rivers to other rivers and streams that were in a similar geophysical setting (see Figure 2 for final stratifications). For example, the Coastal Plain of NC has extremely little topographic relief whereas the mountains of the Southern Blue Ridge are topographically diverse. As such, the resilience attributes of rivers in these areas will be very different and comparing these rivers to each other would not yield a representative analysis.

To create the stratification units we first started the freshwater ecoregional boundaries as defined by World Wildlife Fund (see Abell et al. 2008). This created a stratification unit that contained the networks in the Tennessee Freshwater Ecoregion which all drain to the Mississippi River through the Tennessee River Basin. This freshwater ecoregion has a very distinct and separate zoogeologic history and freshwater biota in comparison to the Atlantic-draining networks in NC (Abell et al. 2008). Through expert discussion and review, we agreed that the South Atlantic freshwater ecoregion was too large to distinguish between rivers and streams in the Piedmont area versus the Coastal Plain area. As such, to define these stratification units we used the terrestrial ecoregional boundaries creating a Piedmont stratification unit and a Coastal Plain stratification unit (Figure 2). We selected this methodology because the terrestrial ecoregional boundaries nearly exactly matched with the Ecological Drainage Units often used to stratify freshwater systems (Higgins et al. 2005).

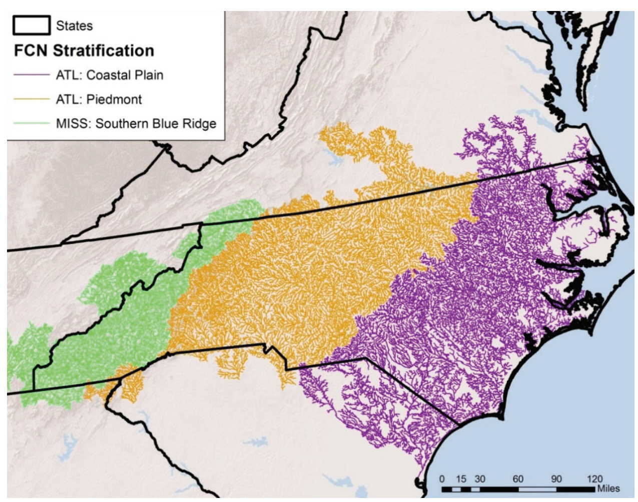


FIGURE 2. Stratification used in NC Freshwater Resilience Analysis. Units were defined by the South Atlantic freshwater ecoregions (for the Piedmont and Coastal Plain) or the Tennessee freshwater ecoregions (for the Mountains).

Assessment Methods

For the NC freshwater resilience analysis, we used a very similar approach to what was used by TNC in the Northeastern US (see Anderson et al. 2013), however certain attributes and analyses were adjusted to be more accurate for the NC context. In total, we developed 12 primary factors believed to contribute to the resilience of the FCN, all of which tie back to one of the six essential elements for resilience defined in the Introduction. The 12 factors quantified either a physical property of the stream network or an ecological condition metric for the network. In the next section, we define these factors and the general methods used to evaluate them across each FCN. Included in this description is the mechanism by which all the analyzed attributes were then combined to create one overall resilience score.

Resilience Attributes: Definitions and Methods

Through expert workshops and review of maps and data, we analyzed 12 resilience attributes for scoring FCNs' resilience. The following metrics (and their relationship to the six characteristics that lead to resilience) were used to score the networks for resilience:

- **Physical Properties**: factors that create habitat heterogeneity within a network and allow more options for species to move:

    1) Network complexity – the number of stream size classes in a FCN
    2) Length of connected network – linear connectivity
    3) Number of gradient classes – diversity of geophysical settings
    4) Number of temperature classes – diversity of geophysical settings
    5) Elevation range – diversity of geophysical settings
    6) Baseflow Index – access to groundwater

- **Condition Characteristics**: factors that maintain important functions and processes:

    7) Impervious surface index – Water Quality
    8) Floodplain naturalness index – Lateral Connectivity
    9) Adjusted cropland index – Water Quality
    10) Cumulative dam storage index – In stream flow regime
    11) Cumulative % waterbody index – In-stream flow regime
    12) Cumulative water use index - In-stream flow regime

Below we describe each of these characteristics and the methods used to calculate them in more detail.

Physical Properties

Network Complexity

Network complexity refers to the variety of different sized streams and rivers contained in a network. Stream size and network complexity are critical factors in determining aquatic biological assemblages (Hitt and Angermeier, 2008). The "river continuum concept" (Vannote et al. 1980) provides a description of how differences in the physical size of the stream catchment relates to differences in stream characteristics, from small headwater streams draining local catchments to large rivers draining entire basins. The changes in physical habitat, water volume, and energy source, as streams grow in size are correlated with predictable patterns of change in the aquatic biological communities. Because biota and physical processes change with size classes, our assumption is that networks containing a variety of stream and river sizes will provide more varied potential habitats, including habitat refugia, and will be able to retain more of their native freshwater species composition even as the climate and hydrological regimes change in the future.

The Northeast Aquatic Habitat Classification (Olivero and Anderson 2008) delineated seven size classes for streams based on their catchment drainage area: headwater, creek, small river, medium tributary, medium mainstem, large river, and great river. These classes were determined by studying similarities in the size classes and biological descriptions across the various state classification systems, and by studying the distributions of freshwater species across size classes. For the purposes of the NC analysis, the two largest river sizes, large and great rivers, were merged given few great river systems occur in NC (see Table 1).

TABLE 1. River and Stream classification system for NC delineating size classes for streams based on their catchment drainage area.

Size class	Type	Size
1a	Headwaters	0 < 3.861 sq.mi.
1b	Creeks	>= 3.861 < 38.61 sq.mi.
2	Small Rivers	>= 38.61 < 200 sq.mi
3a	Medium Tributary Rivers	>= 200 < 1000 sq.mi.
3b	Medium Mainstem Rivers	>= 1000 < 3861 sq.mi
4 and 5	Large and Great Rivers	>= 3861 sq.mi

Network complexity was measured as a count of stream and river size classes found within a functionally connected network, as defined in the Northeast Aquatic Habitat Classification (Olivero and Anderson 2008). The metric ranged from 1 to 6, and was calculated and coded systematically for each network. Each network was automatically given the presence of the smallest headwater stream class, 1a, because we know our source hydrography does not map all of the tiny headwater streams and most likely each network had some unmapped occurrences of these smallest headwater streams connected to them. Subsequent counting of the presence of larger sized streams and rivers depended on the total length of these habitats in a network being >= 1.6 km (1 mi) to ensure that we counted only size classes being present if they had a substantial expression in the stream network. For example, a total of 0.5 km length of river length in size class 2 in a network was not counted as an example of that size class because it was too small to represent a full expression of the biota and processes expected for a size 2 river. We also summed the total length of all river habitat (size 2+) and flagged networks that contained >= 1.6km (1 mi.) of rivers to separate out headwater-creek only networks from networks containing rivers. Please note this threshold (1.6km for all river sizes) was a modification to the more restrictive length thresholds used for medium to large rivers in Anderson et al. 2013 given expert feedback in NC review meetings.

Length of the connected network

Connectivity within a network of streams is essential to support freshwater ecosystem processes and natural assemblages of organisms. It enables water flow, sediment and nutrient regimes to function naturally, individuals to move throughout the network to find preferred feeding and spawning conditions, and, in times of stress, it enables individuals to relocate where conditions are more suitable for survival (Pringle 2001). We assumed that areas with greater linear connectivity are more resilient to environmental change.

We measured linear connectivity by calculating the total length (km) of each FCN (Figure 3). This provided a quantitative assessment for comparison among networks. We used only dams and topmost headwaters as barriers. Road-stream crossings and waterfalls were not used due to uncertainty whether these features were true barriers to movement and inconsistencies in mapping these features across the region.

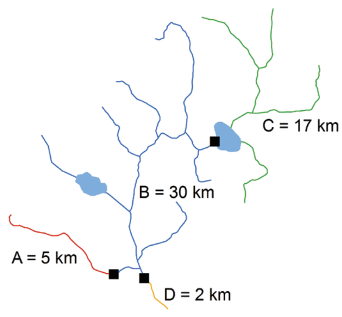


FIGURE 3. Length of the Connected Network. This figure illustrates the total kilometers of streams for each network, calculated for streams of any size class between fragmenting dams or upper headwaters (i.e. Figure 1 but with lengths calculated).

Number of Gradient Classes

Effectively conserving freshwater biodiversity in a changing climate requires protecting geophysical settings that, over an evolutionary timescale, ultimately drive patterns of diversity (Anderson and Ferree 2010, Palmer et al. 2009, Rieman & Isaak 2010). For stream networks this includes variation in a number of factors, such as gradient and temperature, which have long been identified as important in shaping freshwater biodiversity (Higgins et al. 2005). Networks with high variation in these properties capture the variety of available microclimates, habitats, and flow velocity conditions that species can exploit during rearrangement in response to environmental changes. Incorporating information on geophysical diversity allows conservation biologists to better encompass genetic and phenotypic diversity by conserving diverse habitat representations across river basins with appropriate redundancy (Rieman & Isaak 2010). We quantified geophysical diversity for three factors: gradient, temperature, and elevation range.

To assess the number of gradient classes in a connected stream network, we first classified every stream and river segment into one of six possible slope classes, following the gradient class recommendations for streams and rivers in the Northeast Aquatic Habitat Classification.

1: Very Low Gradient <0.02%

2: Low Gradient >= 0.02 < 0.1%

3: Moderate-Low Gradient >= 0.1 < 0.5%

4: Moderate-High Gradient >=0.5 < 2%

5: High Gradient >=2 < 5%

6: Very High Gradient >= 5%

The number of distinct gradient classes found in each connected network was tallied and our metric was a count of gradient classes. Following Anderson et al. 2013, we used a minimum criteria of >= 0.8 km (0.5 mi) total length of a class to qualify as present. This ensured that we counted only gradient classes that had a substantial expression in the stream network.

Number of Temperature Classes

Stream temperature sets the physiological limits where stream organisms can persist and temperature extremes may directly preclude certain taxa from inhabiting a waterbody. Seasonal changes in water temperature often cue development or migration, and temperature can influence growth rates and fecundity. Many species that are important in coldwater streams are rare or absent in warmwater streams (Halliwell et al. 1999). Many aquatic species, such as brook trout, have adapted to specific temperature regimes, and are intolerant of even small changes in mean temperatures or lengths of exposure to temperatures above certain limits (Wehrly et al. 2007). Ideally a resilient stream network would span a range of current temperatures offering options for both coldwater and warmwater species and provide connected space for species to stay within their thermal preferences in the future.

The Northeast Aquatic Habitat Classification assigns every stream reach to one of four expected natural water temperature classes, based on the relative proportion of cold water to warm water species in stream fish composition: cold, cool transitional, warm transitional, and warm. Stream reaches were assigned to a temperature class using a Classification and Regression Tree (CART) model based on stream size, local baseflow index, upstream air temperature, and stream gradient (details in Olivero and Anderson 2008). The metric of temperature diversity for this study was a count of the number of temperature classes found in the connected network. To ensure that we counted only temperature classes that had a substantial expression in the stream network, we only counted a temperature class present if it occurred in >= 1.6km (1 mi.) of length in the network. This length threshold was a modification to the more restrictive length thresholds used for rivers in Anderson et al. 2013.

Elevation Range

For each FCN, we subtracted the lowest minimum elevation (meters) from the highest maximum elevation (meters) of the reaches within a FCN to get the net range in elevation encountered within this network. The team felt that networks with larger net elevation ranges provided more thermal microclimate refuges. Larger elevation ranges may be particularly important as cooler air temperatures are encountered at higher altitudes and may give species access to needed cooler microclimates into the future.

This metric was used to help better discern potential variety in temperature classes in a given network. NC has a wide, flat coastal plain where all the rivers and streams fell within one temperature class. As such, in reviewing the results with various experts we agreed we needed a further metric that would allow us to distinguish between FCNs in the coastal plain as concerns temperature. When we evaluated elevation range we all agreed this was a good proxy for temperature class particularly in the coastal plain and added further richness to the other physical variables in the analysis.

Baseflow Index

Groundwater inflow to streams helps maintain a stable and constant discharge throughout the year and is also associated with cooler temperature refugia areas in many stream systems. We hypothesize that networks with a higher proportion of streams and rivers with higher baseflow will be more resilient to climate change warming and alteration of current precipitation patterns, particularly droughts.

Mean baseflow index within NHDPlus v1 local catchments was calculated for each reach using the USGS Baseflow Index Grid (Wolock 2003). This 1-km raster (grid) dataset for the conterminous United States was created by interpolating baseflow index (BFI) values estimated at U.S. Geological Survey (USGS) stream gages. Baseflow is the component of streamflow that can be attributed to groundwater discharge into streams. It can range from 100 for a stream where groundwater discharge makes up 100% of the stream flow to 0 where no discharge is contributed from ground-water.

We calculated the km of stream and rivers lines in each of the following categories of baseflow within a network.

1. baseflow index class 0-29
2. baseflow index class 30-39
3. baseflow index class 40-49
4. baseflow index class 50-59
5. baseflow index 60+

We then converted the lengths to percent of total length of each network that fell into the five categories and created a summary network score as follows:

5 *(% in baseflow class 5) +

4 * (% in baseflow class 4) +

3 * (% in baseflow class 3) +

2 * (% in baseflow class 2) +

1 * (% in baseflow class 1).

Thus the baseflow summary score ranged from 500 in very high baseflow settings to 100 in very low baseflow settings.

Condition Characteristics

Impervious Surface Index

Water quality, and consequently the biotic condition in the stream, declines with increasing watershed imperviousness (CWP, 2003, Cuffney et al. 2010, King & Baker 2010, Wenger et al. 2008). The ability of freshwater systems to adapt to disturbance relies on high water quality which in turn results from the land cover and land uses surrounding the river system. Water quality in the region is highly variable due to extensive urban and suburban development, the prevalence of agriculture in valleys and floodplains, and energy extractive activities. We assumed that stream watersheds with few impervious surfaces should, on average, have higher water quality.

Using the 2006 National Land Cover Dataset (NLCD; Fry et al. 2011) Percent Developed Imperviousness 30-m raster, we tabulated the area of impervious surface for each NHDPlus v1 catchment. We accumulated the total impervious surface for the full drainage area of each NHDPlus v1 flowline using the NHDPlus Catchment Attribute Allocation and Accumulation Tool (CA3T; http://www.horizon-systems.com/nhdplus/NHDPlusV1_tools.php#NHDPlus%20Catchment%20Attribute%20Allocation%20and%20Accumulation%20Tool%20%28CA3T%29) and then calculated the percentage of the network drainage area comprised of impervious surface. We used King and Baker (2010) to define impervious surface thresholds and created four classes for the index:

1. Class 1: 0 to <= 0.5% impervious surface
2. Class 2: 0.5% to <= 2%
3. Class 3: 2% to <= 10%
4. Class 4: > 10%

For each stream reach we calculated the percent of km of the network in each impact class, weighted each class (1-4) and summed the values to create the index as follows: 4 x % in impervious class 4 + 3 x % in impervious class 3 + 2 x % in impervious class 2 + 1 x % in impervious class 1. Values ranged from 100 to 400 with 100 indicating FCNs with very low amounts of impervious surface in the network catchment.

Floodplain Naturalness Index

In natural freshwater systems, the floodplain is periodically inundated with water, resulting in the exchange of nutrients, sediments, and organisms necessary for long-term ecosystem health. Periodic floods maintain the physical stream channel, facilitate interactions between terrestrial and freshwater ecosystems, and create habitat for aquatic organisms that feed or spawn in the floodplain. These processes are necessary to support a fully functional freshwater ecosystem. Sustaining the processes requires connectivity between the channel and floodplain, termed “lateral connectivity” (Noe and Hupp, 2005). Naturally vegetated and connected floodplains store flood waters and sediment, reducing channel scour and bank erosion. In addition, maintaining and restoring the floodplains and riparian wetlands to a more natural condition can foster infiltration that serves to recharge groundwater aquifers, helping mitigate extreme low flows associated with more frequent drought conditions.

We assumed that areas with more intact floodplains have the potential for increased lateral connectivity and thus greater resilience to climate change and other disturbances. For each connected network, we mapped the Active River Area (ARA; Smith et al. 2008) of all streams and rivers. The ARA is the area of dynamic interaction between the water and the land through which it flows, and includes the river meander belt, floodplain zone, riparian wetlands, and floodplain terraces. We quantified the extent of four land cover types (natural, agricultural, low intensity developed, and medium and high intensity developed) in this zone using data from the 2006 NLCD. For each FCN, we calculated the total percentage of floodplain area in each class and then quantified the degree of development using the following weighted index: (1 * % high intensity developed) + (0.75 * % low intensity developed) + (0.25 * % agriculture.) + (0 * % natural). The index ranged from 0 for a floodplain in completely natural cover to 100 for a completely developed floodplain.

Adjusted Cropland Index

New techniques have been developed (Baker et al. 2006) to assess the potential for natural land cover to buffer the transport of nutrients across the landscape and into the stream system. This type of analysis provides a way to evaluate how the configuration of cover types in the landscape surrounding a given stream reach can buffer nutrient flow, and consequently to indicate which streams are best buffered. The metric is essentially a calculation of the percent cropland in a catchment adjusted down to show how well nutrient delivery from upstream cropland is buffered along flow paths to likely reduce nonpoint source delivery to streams

We assumed that better buffered systems (which should on average have higher water quality) will be more resilient to climate change and other disturbances. A similar analysis was done for the Northeastern portion of NC and Southeastern VA and the results indicated that substantial buffering differences existed based on land cover in the surrounding landscape. Calculating this metric involved computing the transport distances of water from "source" pixels (e.g., row crop agriculture) through downslope, potential nutrient "sink" pixels (e.g., forest and/or wetlands) along flow pathways to streams. The output represents distance through buffer cells to the stream along a flow pathway. The more "sink" cells the water passes through the better buffered the stream. The inverse of the resultant buffer width for each cropland pixel was calculated as 1/(buffer width + 1). The inverse buffer width was then summed for each NHDPlus catchment and multiplied by the pixel area to calculate an adjusted percent cropland value. Based on discussions with experts, we agreed that poorly buffered cropland in headwaters has a more detrimental impact than poorly buffered cropland in larger river systems. As such, we weighted the adjusted percent cropland in headwater catchments twice as much as in non-headwater catchments. Per feedback from reviewers, we also treated shrub/scrub land cover from the 2006 NLCD as a nutrient sink in addition to forest and wetland cover.

To calculate an index, we assigned the percent adjusted cropland for each catchment (after weighting headwater values twice) in each FCN into four classes based on thresholds used in Mattson and Angermeier 2007.

1. Class 1: < 2%
2. Class 2: 2 – 9%
3. Class 3: 10 – 49%
4. Class 4: > 50%

We then calculated the percent of total area in each class and calculated an adjusted % cropland index as follows: (% area in class 1 * 1) + (% area in class 2 * 2) + (% area in class 3 * 3) + (% area in class 4 * 4). Values of the index ranged from 100 to 400 with 100 indicating all cropland is well buffered with likely low non-point source contributions to streams while values of 400 represent FCNs for which more than 50% of all cropland is poorly buffered with likely high non-point source contributions.

Instream Flow Regime

The last three condition metrics (cumulative dam storage, cumulative percent waterbody area, and cumulative water use) were calculated to estimate the degree to which instream flows have been altered in NC rivers and streams. The instream flow regime, including the amount, frequency, duration and seasonality of flow through a stream, plays a critical role in shaping the communities that live in freshwater systems (Poff et al. 1997, Postel & Richter 2003, Poff et al. 2010). Alterations in flow regime due to changes in patterns of precipitation (e.g. increasing drought frequency), water withdrawals, land use and associated runoff, and dam operations are common throughout the Southeast. These alterations have had, and will in the future have, significant negative impacts on the species and communities that live in the region's waters. The specific responses of instream biota to altered flow regimes are not well understood, though a growing body of literature has begun to address this (Carlisle et al. 2010, Fitzhugh and Vogel 2010). We assumed that streams with more natural flows (i.e. those with flows that are less altered) will be more resilient to environmental changes, and to climate change in particular. Therefore, we propose here to assess the degree of flow alteration in NC rivers. The metrics used were determined based on expert knowledge and results from a flows analysis conducted by Kimberly Meitzen (see Meitzen 2013).

Cumulative Dam Storage Index – Flow Alteration Metric

We assumed that stream networks with natural, less altered flows are more resilient to environmental and climatic changes. We created an index to measure the relative risk of flow alteration by dams for each connected stream network, by calculating how much of each river's (size 2 or greater) mean annual flow was potentially stored by upstream impoundments (Fitzhugh and Vogel 2010, Zimmerman 2006).

Through searching various databases we were able to find dam storage information for 71% of the dams used to define the FCNs. The total cumulative storage potential of all upstream impoundments was simplified to place all river reaches into one of five risk classes (derived from Zimmerman 2006):

1. very low: <2%
2. low: 2-10%,
3. moderate: 10-30%,
4. high: 30-50%,
5. severe: 50%+

Next, the risk values for all river reaches in a network were combined using a weighted index based on the percentage of river reach miles in each alteration class as follows:
(% river miles in class 1 * 1) + (% river miles in class 2 * 2) + (etc.)

After consultation with experts in NC, we calculated the index for river FCNs and for headwater FCNs and then we summed these two indices into a single index whose values ranged from 100 to 722. Higher numbers indicate a network where every river reach has the potential for severe alteration by impoundments.

After examining these results with local experts we determined that this method did not work well for the Piedmont region of NC. To better estimate flow alteration in the Piedmont, we used hydrologic flow data calculated for HUC12 watersheds in NC by Research Triangle International (RTI) using their proprietary WaterFALL model (https://waterfall.rti.org). This data was only used for FCN's in the Piedmont subregion for which at least 60% of the FCN contributing area had HUC12 data. Using the RTI data, we calculated the percent change in flow from baseline (1970's) to current for the following three ecologically-based flows: 1) stress flow in July; 2) establishment of growing season flows in May; and 3) spawning cue flows in January. The values for each of the three variables were assigned to one of six classes based on natural breaks. For each FCN, we calculated the percent of HUC12 area in each class. An index of alteration for each flow variable was then calculated as follows: (% area in class 1 * 1) + (% area in class 2 * 2) + (% area in class 3 * 3) + (% area in class 4 * 4) + (% area class 5 * 5) + (% area class 6 * 6). A final metric was created from these three indices by summing the indices and dividing by three. Thus, if the value was the worst in all three, the score was the worst. If there was one really bad score and two good scores, then the resultant value was in the low to low middle range. For Piedmont FCNs with less than 60% of their contributing area covered by the RTI data (n = 38), we used the dam storage index as described above and also used in the Mountains and Coastal Plain subregions. For the Piedmont subregion, the dam storage and RTI flow alteration were rescaled so their values had the same numeric range.

Cumulative Percent Waterbody Index – Flow Alteration Metric

The degree of flow alteration a system experiences can have a dramatic impact on in-stream biota and system function. We calculated an index of percent waterbody area to accompany the dam storage index to better gauge flow alteration. We obtained data developed by the Southeast Aquatic Resources Partnership (SARP) for a regional flow assessment (Davis et al. 2012), in which a proxy for flow alteration was developed based on the extent of lake/pond acreage within and upstream of each catchment in the high resolution (1:24,000) NHD waterbody dataset. The percent waterbody area was used as a proxy for flow alteration since most lakes in the Southeast are not natural and represent a reservoir or impoundment of some type.

The goal of this metric was to provide a proxy for flow alteration assuming that a higher amount of artificial water bodies in a catchment leads to increased evaporative losses from the river systems. As such, we only wanted to include water bodies that were not natural. We thus removed known natural lakes from the NHD high resolution waterbody data. We also excluded coastal areas whose elevation was less than 2 meters assuming this would be sufficient to exclude most natural water bodies in low lying areas along the coast. We then calculated the local and cumulative area of NHD high resolution water bodies in each catchment. We chose to use the cumulative waterbody metric and calculated the percentage of cumulative waterbody area as follows: (cumulative waterbody area/ cumulative drainage area) * 100. Catchments were then assigned to one of four different classes:

1. Class 1: 0% land covered by water bodies
2. Class 2: 0-2% land covered by water bodies
3. Class 3: 2-5% land covered by water bodies
4. Class 4: >5% land covered by water bodies

We then calculated the percent of total area in each class and created an index as follows: (% area in class 1 * 1) + (% area in class 2 * 2) + (% area in class 3 * 3) + (% area in class 4 * 4). Values ended up between 100 and 400 with 100 indicating there were no catchments with any lake or pond acreage in the FCN.

The assumptions and limitations of this metric include that all lakes/ponds and reservoirs other than those initially excluded are considered "artificial." Finally, NHD high resolution water bodies are known to underestimate the amount of artificial water bodies in the state.

Cumulative Water Use Index – Flow Alteration

As a final measure of flow alteration we calculated a cumulative water use index for FCNs by using water withdrawal and return data for NHDPlus catchments provided by RTI. We calculated both a local flow alteration and cumulative flow alteration variable. Local flow alteration was the percent of mean incremental flow (attribute provided in the NHDPlus v1 dataset) consumed by water use, with water use determined by subtracting returns from withdrawals for each catchment. For the cumulative variable, the withdrawal and return data were summed for the entire network drainage area of each NHDPlus catchment, water use was then calculated by subtracting cumulative returns from cumulative withdrawals. The percentage of mean annual network flow (attribute provided in the NHDPlus v1) consumed by cumulative water use was then calculated. We assigned the local and cumulative flow alteration values for each catchment to one of the following six classes informed by varying degrees of alteration associated with natural breaks in the dataset:

1. Class 1: 0 -2%
2. Class 2: 2-5%
3. Class 3: 5-10%
4. Class 4: 10-30%
5. Class 5: 30-50%
6. Class 6: >50%

From here we calculated a weighted index as the percent of catchment area in each impact class multiplied by the corresponding weight (1-6) = (% class 1 * 1) + (% in class 2 * 2) + (% in class 3 * 3) + (% in class 4 * 4) + (% in class 5 * 5) + (% in class 6 * 6) . Values ranged from 100 to 600 where 100 means the catchment has no to minimal flow alteration from water use and 600 indicates significant flow alteration from water use. After reviewing both the local and cumulative flow alteration values, we elected to use cumulative water use as it better represented system-wide flow alteration due to water consumption.

Analysis and Ranking

Physical and condition scores were evaluated separately and then the scores were integrated. First, to ensure consistency in the direction of all variable values, we rescaled all individual factors so that positive scores always represented high or good values for each resilience characteristic. Depending on the distribution of each variable by subregion, we applied various transformations to any non-normally distributed variable (i.e. length) so that it approximated a normal distribution. Next, a correlation analysis was conducted to identify and remove highly correlated (Pearson $r > 80\%$) variables (Table 2). We then calculated the mean and standard deviation of each transformed variable within each region. Using the means and standard deviations, we converted all raw variable scores to standardized normalized scores (z-scores, with mean of zero and a standard deviation of one), so that all variables were on a common scale of relative values for each metric and would have an equal influence on the combined score. For each network, we summed the values for each of the uncorrelated physical properties metrics and divided by the total number of metrics to generate a final index of physical properties. Likewise we summed the values for the condition factors and then divided by the total number of condition factors to create an index of condition. Finally, we summed the physical and condition z-scores to create a resilience score.

TABLE 2. Variables removed in each stratification unit for each type of FCN based on correlation analysis.

Subregion	FCN	Variables Removed
Coastal Plain	River	size count; temperature class
Coastal Plain	Headwater	size count; temperature class
Piedmont	River	elevation range
Piedmont	Headwater	elevation range
Mountains	River	gradient count
Mountains	Headwater	size count

For each FCN type (i.e., headwater versus river FCN), we calculated a combined relative resilience score based on the final score for physical properties and the final score for condition characteristics within its subregion. We created five resilience categories following lessons learned from the resilience analysis done in the Northeast by TNC (Anderson et al. 2013). The categories reflect the resilience score of the network **relative** to the other networks within its subregion. The criteria were as follows:

Highest Relative Resilience

1. Scores for physical properties and condition characteristics were each >=0.5 SD (above average) compared with all functionally connected stream reaches assessed within the same region;
2. The sum of the physical properties and condition scores was at least 1.5 SD above the mean and the lowest score was not below -0.5 SD within the region.

This group contained the highest scoring complex networks. They scored substantially above the mean in both physical properties and condition, or they were extremely high in either physical properties or condition and only slightly low in the other attribute.

High Relative Resilience

1. Scores for physical properties and condition characteristics were each above the calculated mean (> 0 z-unit) but one or both were less than 0.5 SD within their region;
2. The sum of both scores was at least > 1 SD above the mean and the lowest score was not below -0.5 SD for their region.

This group contained the second highest scoring complex networks. They were slightly above the mean in both diversity and condition, or they were well above the mean in either diversity or condition and slightly below the mean in the other attribute.

Mixed Relative Resilience: Condition Low

1. Scores for physical properties were above the calculated mean (> 0) for the region, and condition was at or below zero (the calculated mean).

This group contained complex networks that scored above average in diversity, but at or below average in condition. Their diversity scores were not so high that the network qualified for the high category based on a sum of their diversity and condition scores.

Mixed Relative Resilience: Physical/Diversity Low

1. Scores for condition characteristics were above the calculated mean (> 0) for the region, but the physical property score was at or below zero (the calculated mean).

This group contained complex networks that scored above average in condition, but at or below average in diversity. Their condition scores were not so high that they qualified for the high category based on a sum of their diversity and condition scores.

Low Relative Resilience

2. Networks where the relative scores for physical properties and condition were both at or below zero (the calculated mean).

Comparison with TNC Freshwater Portfolio

Finally, we overlaid and compared the results of this analysis with the results of the Conservancy's portfolio of priority rivers. For the rivers (i.e. the non-headwaters), we overlaid and compared the river FCN resilience results with the Conservancy's freshwater portfolio of priority rivers by subregion. Portfolio rivers contain a selective subset of all rivers that include viable populations of rare species or the best examples of representative river types. The goal of the portfolio was to identify river networks that, if conserved, would collectively protect the full biological diversity of an ecoregion. The freshwater portfolio data for North Carolina was created by translating ecoregional targets and Mott Foundation freshwater priorities (Palmer et al. 2005) to the NHDPlus medium resolution flowlines. In addition, USGS HUC12 watersheds were coded with attributes to flag the headwater and creek portfolio watersheds to allow a consistent representation of headwater and creek priorities in TNC's Eastern Division.

For the headwaters, the Conservancy's portfolio rivers do not co-occur with any of the headwater FCNs because the portfolio does not include headwater stream and creek flowlines. Thus, we used two approaches to compare the headwater FCNs with the priority HUC12s in the freshwater portfolio. In the first, we simply counted the number of HUC12s that contained at least one headwater FCN in each resilience category. For the second approach, we tallied the total number of headwater FCN kilometers in each resilience category that intersected a portfolio HUC12, and repeated the analysis for all the headwater FCNs that did not occur in a portfolio HUC12 watershed.

Results

As described above, we assessed each river network by their relative physical properties score (Figure 4; Map 1) and relative ecological condition score (Figure 5; Map 2) to visually explore the geographic patterns of the results. The combination of the physical and condition scores led to the development of the relative resilience rank categories (Figure 6; Map 3). Finally we mapped the relationship between the resilience results and TNC portfolio rivers (Figure 7; Map 4). We also mapped the resilience rank for the headwater and stream FCNs (Figure 8; Map 5) and their overlap with portfolio headwater and creeks (Figure 9; Map 6).

The summary results of this analysis are inTables 3 and 4 below.

TABLE 3: FCNs with Rivers (n=247)

Resilience Class	Coastal Plain	Piedmont	Southern Blue Ridge
Highest	2	21	1
High	12	14	10
Mixed: Low Condition	22	18	10
Mixed: Low Physical	23	43	10
Low	12	45	4
Total	**71**	**141**	**35**

TABLE 4: FCNs with headwaters only (n=850)

Resilience Class	Coastal Plain	Piedmont	Southern Blue Ridge
Highest	82	25	12
High	24	102	13
Mixed: Low Condition	67	61	10
Mixed: Low Physical	85	83	23
Low	116	118	29
Total	**374**	**389**	**87**

Comparison with TNC Portfolio

The results of the comparison with TNC portfolio sites are summarized in Table 5, below. For more detailed results please see Appendix A. For rivers, we calculated the percent of river kilometers that ranked in the highest two resilience categories (highest and high from above). For headwaters, we looked at the percent of headwater kilometers that intersected portfolio HUC 12 watersheds where the majority occurred in the highest or high resilience categories. The overlap with TNC portfolio rivers was relatively high in both the Coastal Plain (62%) and Piedmont (55%) sub-regions and relatively low in the Mountains (22%). For the headwaters the overlap in the Mountains was the highest (57%) while the Piedmont showed very low overlap (39%). The Coastal Plain headwater systems still had relatively high (53%) overlap.

TABLE 5. Summary of the results of TNC's portfolio rivers and headwaters and relatively high resilience categories.

Subregion	Portfolio Type*	Total length (km) of Functionally Connected Networks (FCNs)	% in/overlapping two highest resilience categories*
Coastal Plain	Rivers	5,578	62
	Headwaters	3,081	53
Piedmont	Rivers	2,529	55
	Headwaters	3,945	39
Mountains	Rivers	1,723	22
	Headwaters	847	57

* *Headwaters are captured by HUC12 watersheds in TNC's freshwater portfolio so overlap was assessed by HUC12 rather than with flowlines as was done for the rivers.*

Summary of Assumptions/Limitations

To ensure the freshwater resilience analysis was tractable and meaningful as well as to ensure the most accurate results possible, we made some assumptions and decisions regarding what items were or were not included in the analysis. Some of these assumptions applied to the whole analysis and some to particular metrics. These include:

- Only functionally connected networks >1.6 km in length were included
- Metrics were only calculated for flowlines with > 1 square mile of drainage area to address stream density inconsistencies in the NHDPlus v1 dataset.
- "Lakes/ponds" and "Reservoirs" in the NHD high resolution dataset and the NHDPlus v1 dataset represent artificial water bodies
- Coastal exclusion area of 2m elevation above sea level was assumed to be sufficient to exclude most natural water bodies from the NHD and NHDPlus datasets in low lying areas along the coast
- NHD and NHDPlus waterbodies underestimate the amount of artificial waterbodies
- Any highly correlated (defined as Pearson r >80%) variables were removed from a particular subregion
- Adjusted percent cropland in headwater catchments was weighted twice as much as in non-headwater catchments
- For all the metrics, the thresholds used to create resilience classes were based on the best available data and/or expert understanding for the project area and the particular attribute
- Various limitations and assumptions were inherited in the *Cumulative Water Use Index – Flow Alteration metric* by default through the use of the WaterFALL model, specifics are available from RTI at *https://waterfall.rti.org.*

Discussion

For NC TNC, the purpose of this analysis is to inform our future freshwater work in the state. We will focus our strategies in priority areas where we can either conserve or build resilience in order to maintain or enhance diversity and function under climatic and environmental change. The results indicate areas of high relative resilience where TNC NC might, for example, work to maintain that resilience by ensuring the network's connectivity or protecting key areas of land or another appropriate strategies. The analysis also indicates areas that are somewhat vulnerable to climate change impacts where we might make efforts to improve resilience by determining the main causal factor limiting the system's resilience and selecting an appropriate strategy. This might include, for example, enhancing the network's connectivity by removing a dam or improving land management to improve water quality. In addition, we hope this work can be useful to our freshwater partners in the state, not only by providing data and analyses, but also by helping to broaden the work across the state to a landscape level approach. We emphasize that local knowledge of any particular network where TNC might decide to work will be needed to inform decisions about appropriate strategies in the area. Moreover, we caution that the limited resources used for environmental conservation, even with careful prioritization, may not be adequate to protect the entire system from all future changes.

It is important to note that this analysis does not assume that the most resilient river networks will necessarily continue to support the same species that are present today. Instead, the analysis assumes that complex, functioning networks likely to support a diversity of aquatic species and communities into the future, even if the suite of species is different. Essentially, we identify stream networks that offer a wide diversity of options and microhabitats for species, but we do not predict exactly how the dynamics between streams and climate will play out. Presumably, the network's species composition will change with climate, and likewise, processes will continue to operate, though not in the same range of variation that they currently do. Thus, a resilient network is a structurally intact geophysical setting that sustains a diversity of species and natural communities, maintains basic relationships among ecological features and key ecological processes, and allows for adaptive change in composition and structure (Anderson et al. 2012).

The factors we chose to analyze were selected not only because of their likelihood to influence biological communities, but also because they could be modeled in a Geographic Information System (GIS). We ended up assessing 12 factors because we found that certain attributes functioned very well in some regions such as the Mountains but less well in others such as the Coastal Plain. For this reason we examined a wide array of variables in order to capture the ecoregional variations within NC. The physical attributes were selected to capture habitat options and the condition attributes were selected to capture the relative intactness of the ecological processes. For example, cumulative impervious cover is correlated with ecological stream degradation through changes in water quality and habitat complexity (Cuffney et al. 2010; Violin et al. 2011, King and Baker 2010, CWP 2003).

When integrated into a single index there were more "far above average" resilient streams and rivers in terms of physical metrics than when looking across the condition metrics (see Maps 1 and 2, respectively). This suggests that condition has become more altered in NC rivers and streams than the physical setting- logical in that condition is more easily influenced by human communities and human uses. Major impacts to physical metrics occur with dams or sub surface activities like mining or potentially shale gas exploration. Most of the river and stream networks with a high physical resilience score (Map 1) are found in the foothills and mountains which reflects the varying topography and large elevation differences in these regions. Few networks scored high on condition metrics (Map 2) even though many of the rivers and streams in the Mountains region are in relatively good condition. This may have been the result of the downstream uses in that network. The networks in the Mountains subregion drain towards the west and, as such, any activities occurring in downstream cities in Tennessee would affect the resilience score of the entire FCN including the headwater portion in NC. Thus, though the headwater river and streams might be in good condition, further down the river network human influences lower the condition score (e.g. the river network in southwestern NC – see Map 2). Additionally, because of the stratification, half the rivers and streams in any unit would inherently be below the mean even if the overall set of networks were relatively intact. River networks in the Piedmont scored relatively low in terms of condition metrics likely due to the density of development in this region.

Characterizing and classifying resilience streams and rivers in NC met with considerable challenges particularly in terms of data availability leading to certain assumptions and estimations during the analysis. We modeled our analysis after a similar one completed for the entire Northeast by TNC's Eastern Division. The Southeast, however, has a large coastal plain with very little elevation change, uncommon or nonexistent in much of the Northeast. As such, we had to modify particular metrics and add in other metrics to be able to account for this difference, among others. Some of these choices were made based on expert knowledge of the area and on which metrics yielded "appropriate" results. For example, we originally did not use the cumulative dam storage metric because of the many data gaps in the dataset, but the proxy of percent waterbody area did not illustrate the magnitude of flow alteration known to exist across the state. As such, we added that metric back in, but the data was insufficient to represent the flow alteration in the Piedmont so we used water use data to estimate flow alteration in only that case. Further, data was limited so this substitute method was only used for those FCNs in the Piedmont that had at least 60% of the area covered by HUC12 watersheds for which we had data. In all other cases (n=38) the dam storage index was used as it was for the other two subregions. Another example of a data adjustment came with the physical metric of temperature classes. Due to the very flat and large coastal plain and the coarse definition of temperature classes, all the rivers and streams were in the same temperature class. In the end, we did not evaluate this metric for the Coastal Plain and instead calculated elevation range and a baseflow index to try to capture the diversity that the number of temperature classes was unable to reflect.

The methods and data involved in the resilience analysis represent a relatively large departure from past approaches that have used biodiversity to identify high priority sites for conservation. As such, we analyzed the overlap between river and streams that were deemed "high priorities" for freshwater biodiversity conservation with the results of the freshwater resilience analysis (see Appendix A). In general, in the Piedmont and Coastal Plain there was significant overlap between highly resilient rivers and portfolio rivers (55% and 62%, respectively). This indicates that many of the resilient river systems also contain high levels of critical biodiversity. In the mountains, this overlap was much lower (only 22%) but there were very few portfolio river kilometers (less than 1%) that fell into the low relative resilience. Most of the high biodiversity rivers in the mountains scored low condition but high diversity in the resilience analysis (about 70%) which, given that the FCN condition is affected by downstream urban uses (see previous discussion), this result makes sense. The portfolio headwaters had greater percentages in the low relative resilience (between 11-15%) category. This may be a consequence of the degradation of many of the headwater areas in North Carolina. In general, the overlap between highly resilient rivers and headwaters and biodiversity priorities was relatively good. Focusing on those regions that score high in both assessments could be a way to narrow the priorities for future freshwater conservation efforts. See Appendix A for detailed results of the overlap between these analyses.

Overall, we hope this analysis will not only inform TNC NC's freshwater work but also help inform the priorities and approaches of our partners. The resilience analysis aims to not only show areas of high relative resilience but also areas of high relative vulnerability. Each of these sites (and those in between) require a different set of strategies to either maintain resilience or to reduce vulnerabilities. We hope that this analysis can be used as the basis for thinking about freshwater conservation at a landscape scale, using the results to assess the best possible strategies for conserving a particular river network.

FIGURE 4; MAP 1. Physical Properties. This map shows the 247 river FCNs and how they compare in terms of their physical properties score which gives a sense of the habitat diversity within the FCN. The FCNs are compared to each other within a defined stratification unit. Habitat diversity is based on the physical properties of the network.

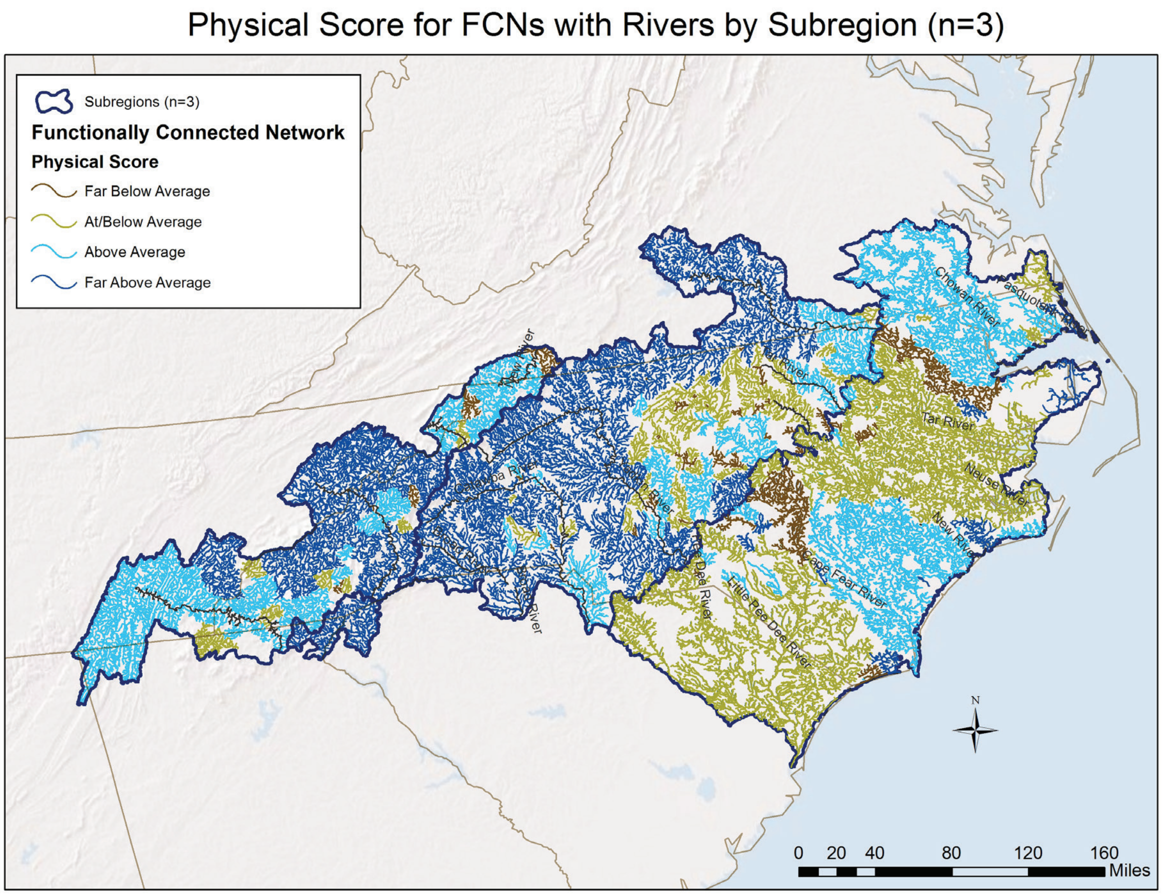


FIGURE 5; MAP 2. Condition Metrics. This map shows the 247 river FCNs and how they compare in terms of their condition characteristics score which gives a sense of how the FCN functions ecologically. The FCNs are compared to each other within a defined stratification unit.

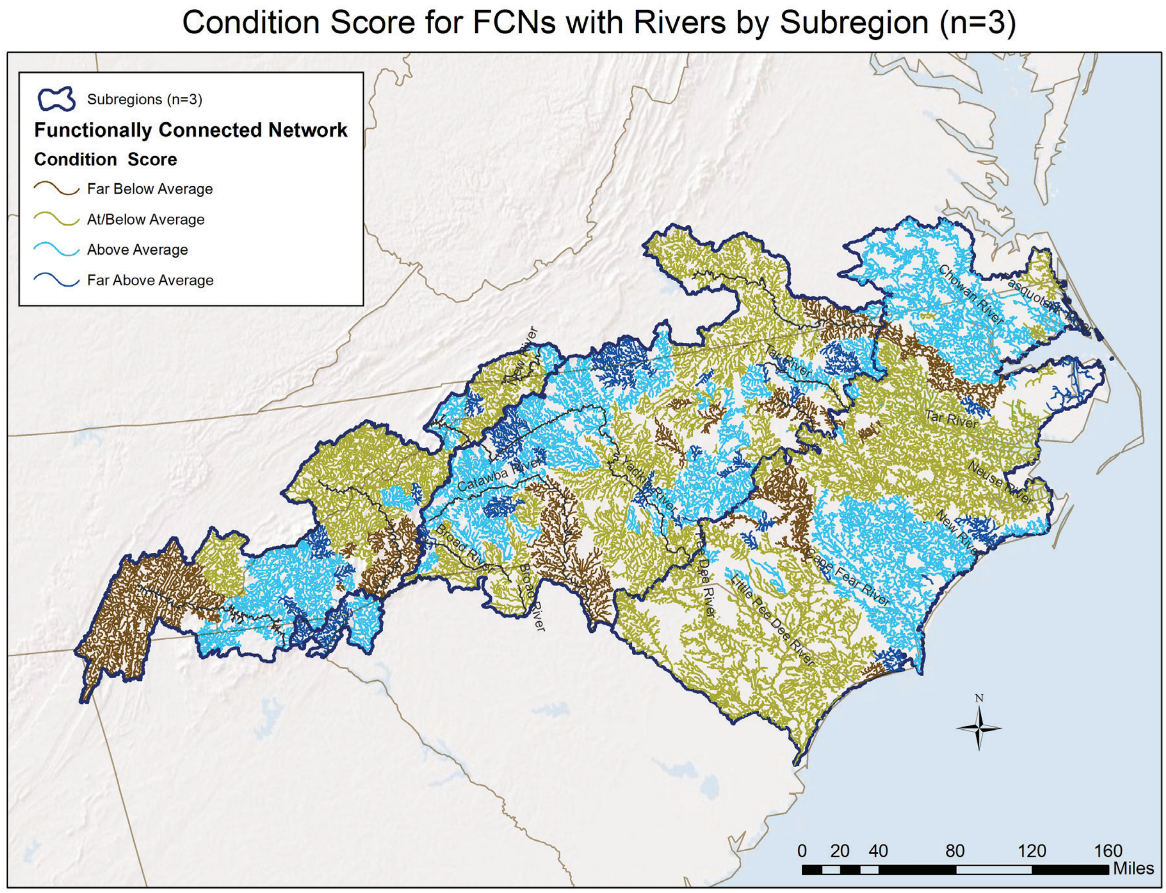


FIGURE 6; MAP 3. River Resilience Score. This map shows the 247 river FCNs displayed by their integrated resilience class. Highest Relative Resilience networks are far above average, High Relative Resilience networks are above average, Mixed networks are high in either diversity or condition but below average in one criteria, and Low scoring networks are below average in both diversity and condition relative to all other networks included in the assessment.

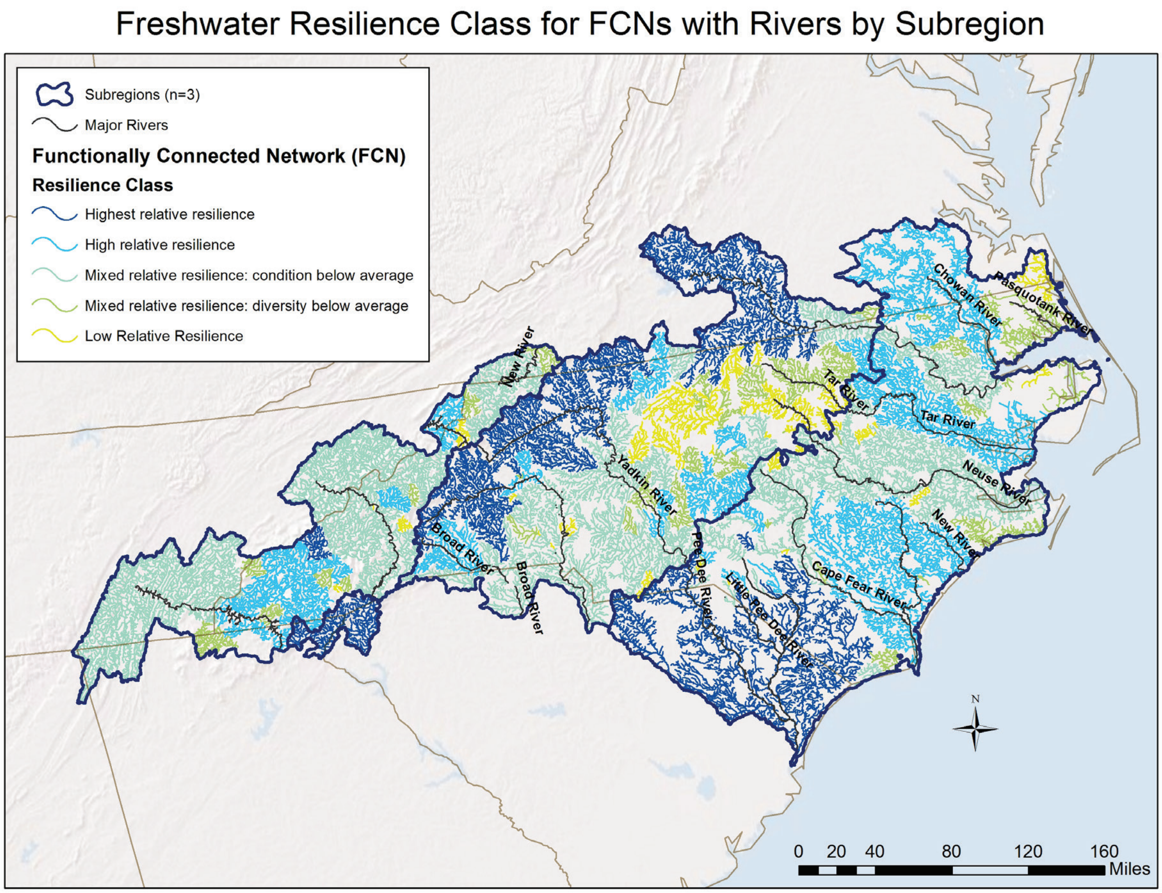


FIGURE 7; MAP 4. Headwater Resilience Score. This map shows the 850 headwater FCNs displayed by their integrated resilience class. Highest Relative Resilience networks are far above average, High Relative Resilience networks are above average, Mixed networks are high in either diversity or condition but below average in one criteria, and Low networks are below average in both diversity and condition in relation to all other networks included in the assessment.

Freshwater Resilience Class for Headwater-Only FCNs by Subregion

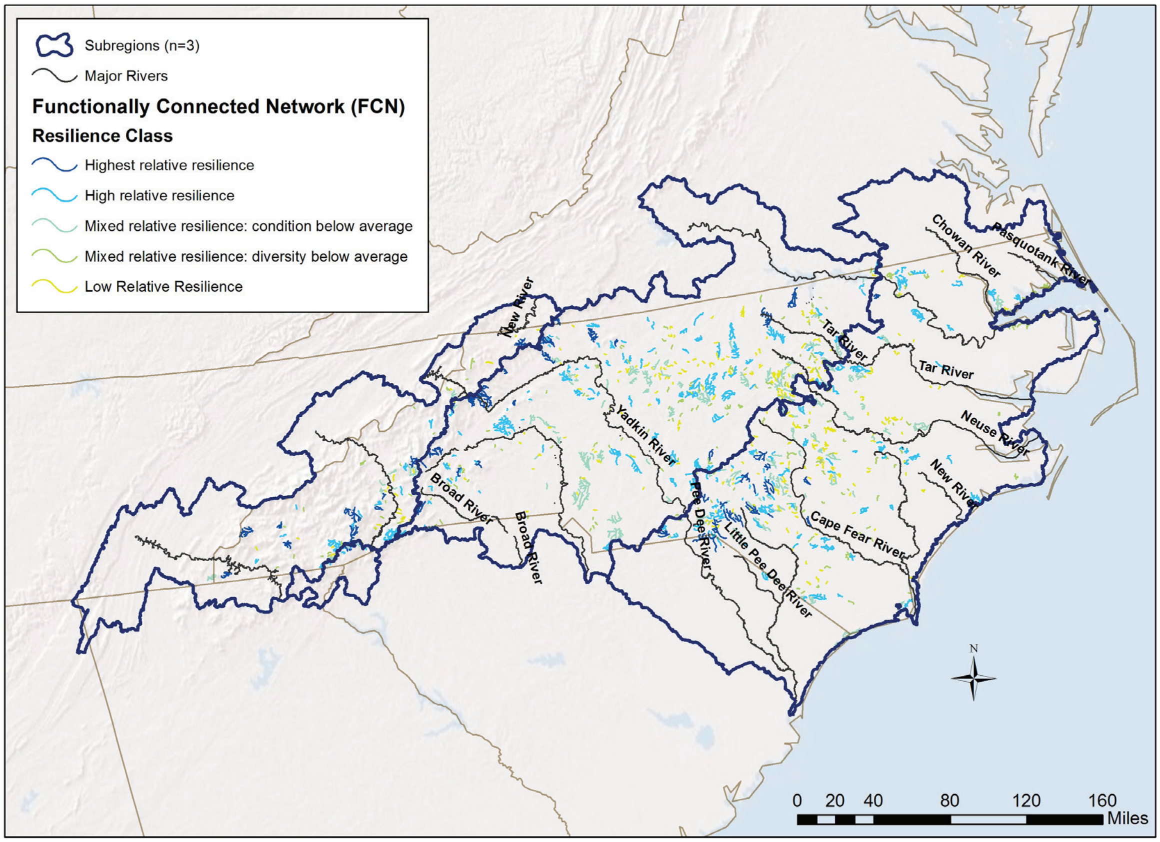


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FIGURE 8; MAP 5. Comparison of TNC's River Portfolio with the River Resilience Rank Categories. This map shows The Nature Conservancy's portfolio rivers grouped by their rank categories for freshwater resilience. Portfolio rivers were identified as the best examples of various river types in the region.

Freshwater Resilience Class for FCNs with Rivers by Subregion with TNC Portfolio Rivers

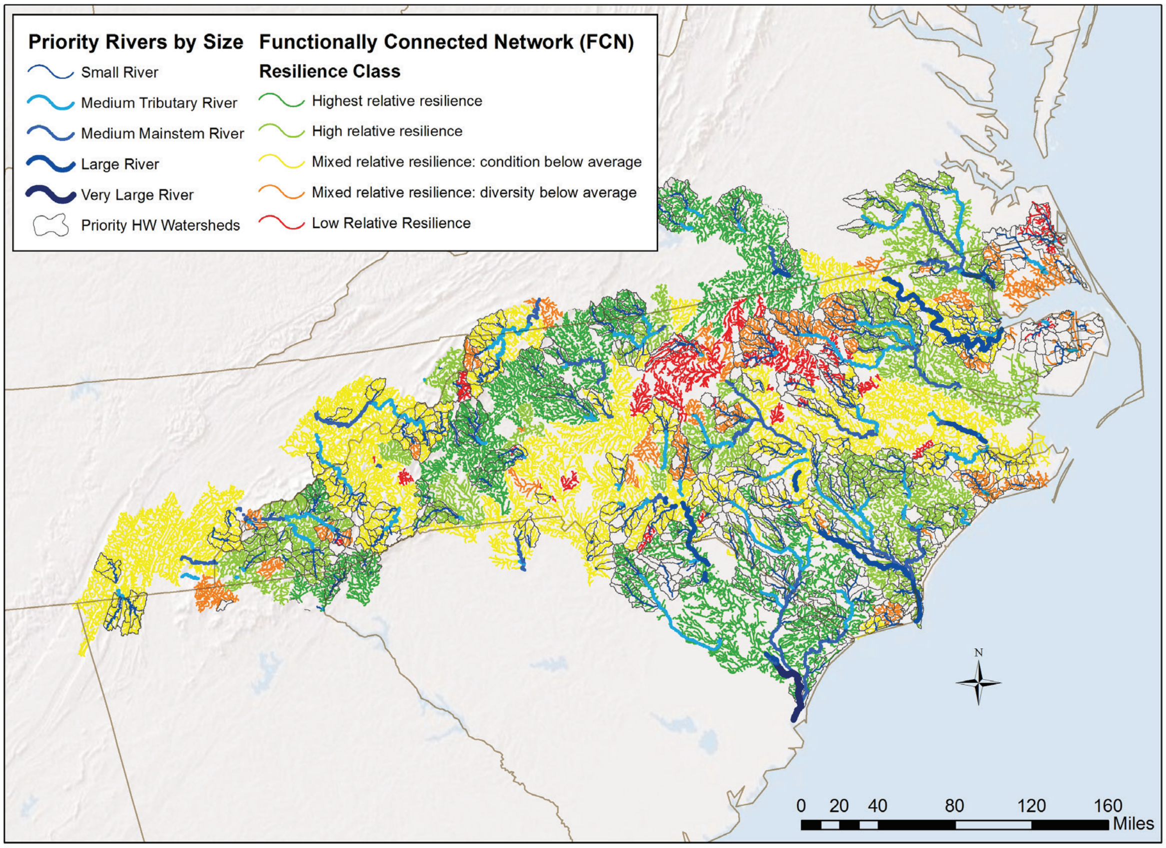
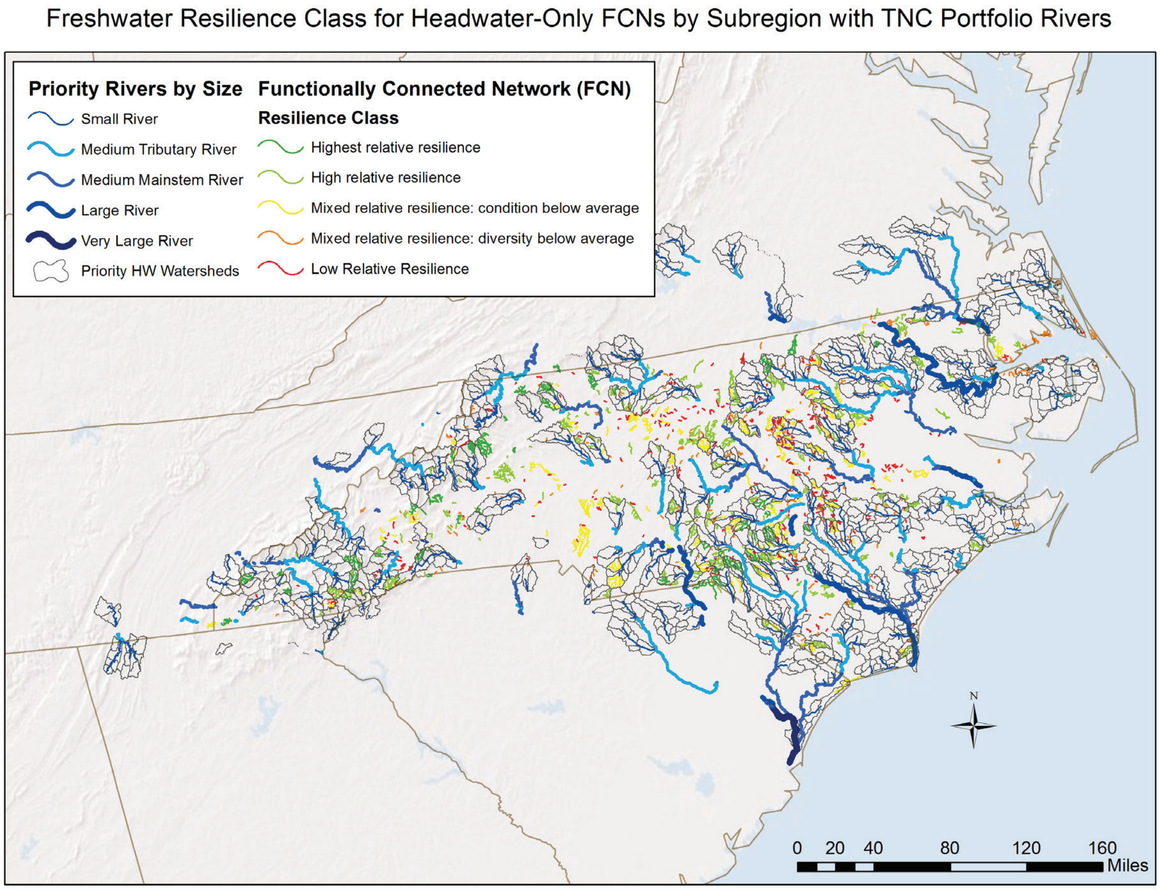


FIGURE 9; MAP 6. Comparison of TNC's Headwaters Portfolio with the Headwaters Resilience Rank Categories. This map shows The Nature Conservancy's portfolio headwaters grouped by their rank categories for freshwater resilience. Portfolio headwaters were identified as the best examples of various river types in the region.



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Appendix A – Comparison of Resilience Analysis with TNC Freshwater Portfolio

Results for River FCNs

TABLE 6. The Nature Conservancy's Freshwater Portfolio Rivers by Relative Resilience Categories: **Coastal Plain** Subregion. In total the Conservancy's portfolio includes 5,578 kilometers of rivers of which 62 percent ranked in the two highest categories for relative resilience in this analysis.

Rank Category	River FCNs (Km)	% of Portfolio
Highest Relative Resilience	1242.25	22.27
High Relative Resilience	2234.82	40.06
Mixed Relative Resilience: Condition Below Average	1509.92	27.07
Mixed Relative Resilience: Diversity Below Average	383.37	6.87
Low Relative Resilience	122.59	2.20
Unranked (no FCNs overlapped with portfolio river lines)	85.47	1.53
Total	**5,578.42**	**100**

TABLE 7. The Nature Conservancy's Freshwater Portfolio Rivers by Relative Resilience Categories: **Piedmont** Subregion. In total the Conservancy's portfolio includes 2,529 kilometers of rivers of which 55 percent ranked in the two highest categories for relative resilience in this analysis.

Rank Category	River FCNs (Km)	% of Portfolio
Highest Relative Resilience	948.45	37.50
High Relative Resilience	452.36	17.88
Mixed Relative Resilience: Condition Below Average	488.83	19.33
Mixed Relative Resilience: Diversity Below Average	383.73	15.17
Low Relative Resilience	247.79	9.80
Unranked (no FCNs overlapped with portfolio river lines)	8.24	0.33
Total	**2,529.40**	**100**

TABLE 8. The Nature Conservancy's Freshwater Portfolio Rivers by Relative Resilience Categories: **Mountains Subregion.** In total the Conservancy's portfolio includes 1,723 kilometers of rivers of which 22 percent ranked in the two highest categories for relative resilience in this analysis.

Rank Category	River FCNs (Km)	% of Portfolio
Highest Relative Resilience	38.75	2.25
High Relative Resilience	341.07	19.79
Mixed Relative Resilience: Condition Below Average	1,198.35	69.54
Mixed Relative Resilience: Diversity Below Average	97.11	5.64
Low Relative Resilience	16.90	0.98
Unranked (no FCNs overlapped with portfolio river lines)	31.16	1.81
Total	**1,723.34**	**100**

Results of Headwater FCNs

TABLE 9. The Nature Conservancy's Freshwater Portfolio HUC12 watersheds and Relative Resilience Categories of Headwater Functionally Connected Networks**: Coastal Plain** Subregion. Of the 3,081 km of headwater FCNs, 53% intersected portfolio HUC12 watersheds with the majority of those occurring in the two highest categories for relative resilience in this analysis.

Rank Category	HUC12s (#)	% of HUC12s	In HUC12 (km)	% in HUC12	Out HUC12 (km)	% out HUC12
Highest Relative Resilience	19	17.76	389.67	23.75	88.29	6.13
High Relative Resilience	37	34.58	506.42	30.87	538.06	37.36
Mixed Relative Resilience: Condition Below Average	34	31.78	385.34	23.49	346.61	24.06
Mixed Relative Resilience: Diversity Below Average	34	31.78	167.82	10.23	243.84	16.93
Low Relative Resilience	40	37.38	191.15	11.65	223.52	15.52
Total	**107[a]**	**100.00**	**1640.40**	**100.00**	**1440.32**	**100.00**

Notes:

[a]: This value reflects the total number of HUC12s that contained at least one Headwater FCN. This is not a true column sum because a HUC12 could contain multiple headwater FCNs that were in different rank categories.

TABLE 10. The Nature Conservancy's Freshwater Portfolio HUC12 watersheds and Relative Resilience Categories of Headwater Functionally Connected Networks: **Piedmont** Subregion. Of the 3,945 km of headwater FCNs, 39% intersected portfolio HUC12 watersheds with the majority of those occurring in the two highest categories for relative resilience in this analysis.

Rank Category	HUC12s (#)	% of HUC12s	In HUC12 (km)	% in HUC12	Out HUC12 (km)	% out HUC12
Highest Relative Resilience	11	13.10	263.67	17.30	413.63	17.08
High Relative Resilience	36	42.86	483.32	31.72	909.43	37.56
Mixed Relative Resilience: Condition Below Average	25	29.76	478.55	31.40	650.14	26.85
Mixed Relative Resilience: Diversity Below Average	29	34.52	126.30	8.29	177.17	7.32
Low Relative Resilience	24	28.57	172.07	11.29	271.05	11.19
Total	**84[a]**	**100.00**	**1523.90**	**100.00**	**2421.41**	**100.00**

Notes:

[a:] This value reflects the total number of HUC12s that contained at least one Headwater FCN. This is not a true column sum because a HUC12 could contain multiple headwater FCNs that were in different rank categories.

TABLE 11. The Nature Conservancy's Freshwater Portfolio HUC12 watersheds and Relative Resilience Categories of Headwater Functionally Connected Networks: **Mountain** Subregion. Of the 847 km of headwater FCNs, 57% intersected portfolio HUC12 watersheds with the majority of those occurring in the two highest categories for relative resilience in this analysis.

Rank Category	HUC12s (#)	% of HUC12s	In HUC12 (km)	% in HUC12	Out HUC12 (km)	% out HUC12
Highest Relative Resilience	7	25.93	210.06	43.17	122.59	34.06
High Relative Resilience	10	37.04	176.59	36.29	33.36	9.27
Mixed Relative Resilience: Condition Below Average	1	3.70	12.64	2.60	110.80	30.79
Mixed Relative Resilience: Diversity Below Average	11	40.74	44.80	9.21	35.90	9.97
Low Relative Resilience	7	25.93	42.51	8.74	57.25	15.91
Total	**27[a]**	**100.00**	**486.60**	**100.00**	**359.90**	**100.00**

Notes:

[a:] This value reflects the total number of HUC12s that contained at least one Headwater FCN. This is not a true column sum because a HUC12 could contain multiple headwater FCNs that were in different rank categories.