Eastern Brook Trout Conservation Portfolio, Range-wide Habitat Integrity and Future Security Assessment, and Focal Area Risk and Opportunity Analysis

TROUT UNLIMITED

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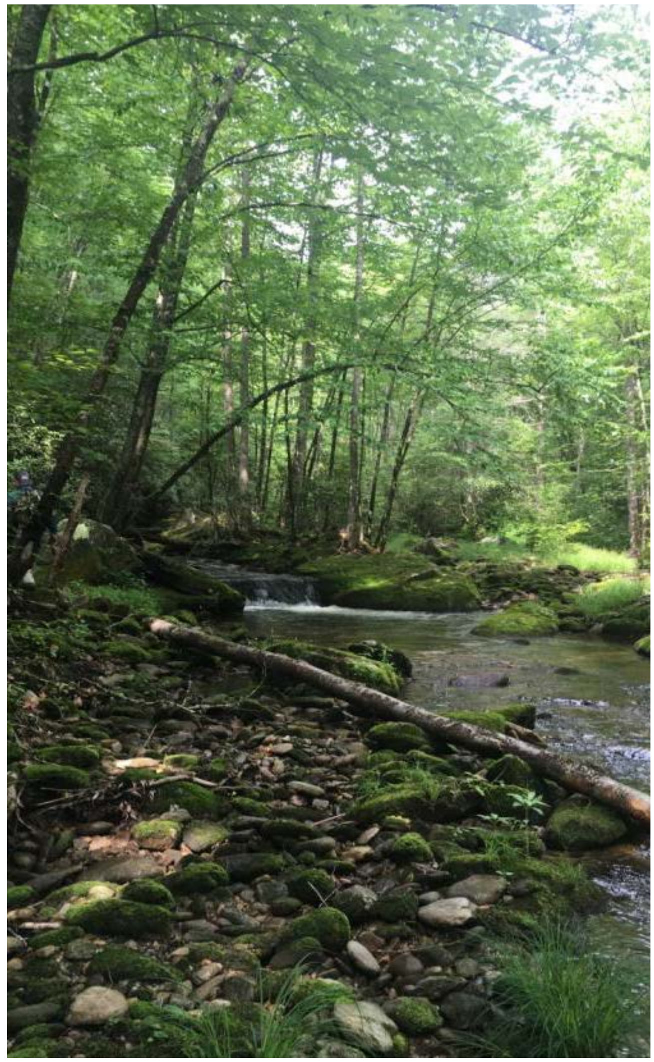

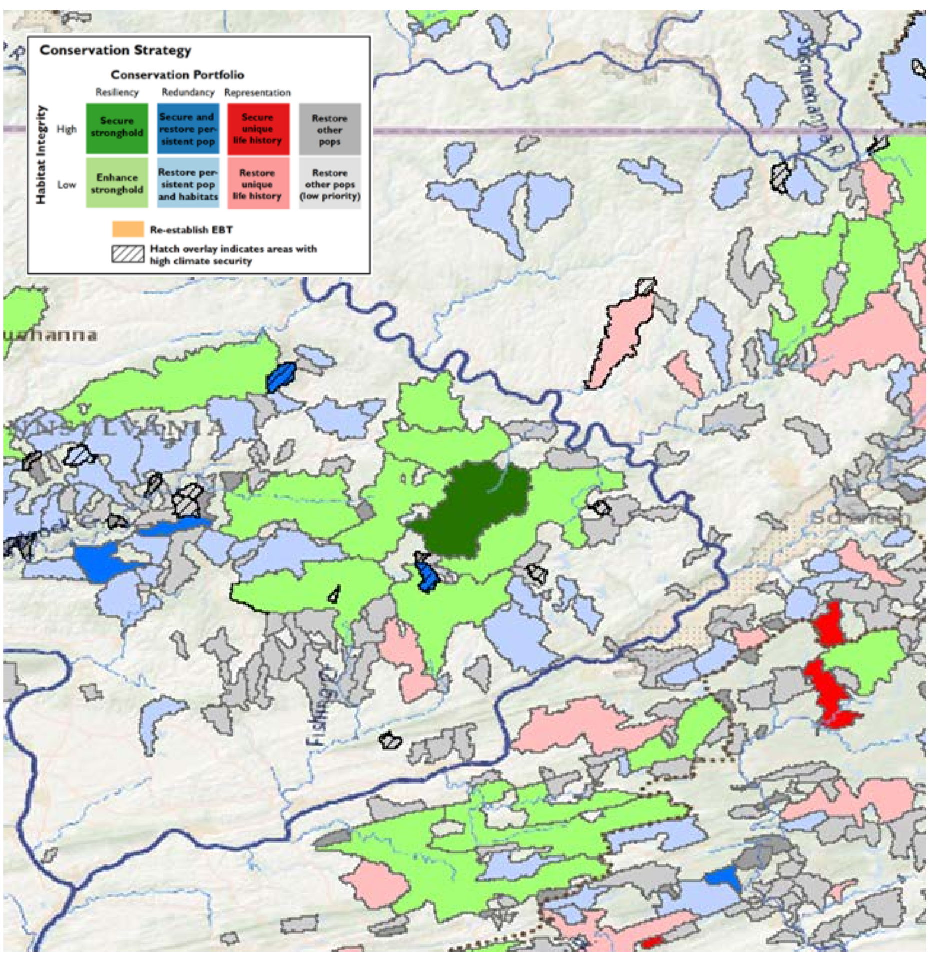

Executive Summary

Trout Unlimited has developed three conservation planning products to help identify strategic conservation opportunities and evaluate potential projects within the eastern range of brook trout (*Salvelinus fontinalis* or EBT). Each product gathers and interprets spatial data related to the pattern of EBT populations, their habitats, and threats to those habitats. The basic unit of analysis and summary for all three products is the Eastern Brook Trout Joint Venture's EBT population patch. This project was supported by funding from the National Fish and Wildlife Foundation.

- The ***Conservation Portfolio*** applies the 3-R framework (Resiliency, Redundancy, and Representation) to evaluate each EBT population patch for its resiliency to disturbances, likelihood of demographic persistence, and representation of genetic, life history, and geographic diversity. Key data sources include the Eastern Brook Trout Joint Venture patch characteristics, stream habitat classification data, and models of stream temperature and EBT probability of occurrence.

- The ***Range-wide Habitat Integrity and Future Security Assessment*** uses broad-scale GIS information to characterize EBT patches and adjacent unoccupied HUC12 subwatersheds based on the current pattern of habitat alteration and anticipated threats. Factors related to agricultural land use, riparian vegetation, road densities, stream crossings, acid deposition, and stream temperature are summarized to assign a percentile score to each patch or subwatershed.

- Four ***Focal Area Risk and Opportunity Analyses*** for the Connecticut, Delaware, Susquehanna, and Chesapeake headwaters add regional data sources to provide additional resolution on habitat integrity and threats within specific geographies.

Taken together, the products characterize the key elements of population diversity and the continuum of viability, habitat condition, and vulnerability present in EBT populations. The unique attributes of each population are interpreted to reflect the corresponding conservation strategies they likely require. For landscapes, the products serve as a population-scale filter for identifying priorities, needs, and opportunities at spatial scales ranging from regions, states, watersheds, or individual land management agencies. For individual populations, the products place local EBT resources within a range-wide context. The products can be used with existing decision support tools and local information to identify projects to benefit EBT.

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Cover photos: Clockwise from top left Eastern Brook Trout (Jon David Nelson/Flickr), Lost Cove Creek, NC (Matt Mayfield), Buck Creek, NC culvert replacement (Damon Hearne).

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Introduction

Within their eastern range in the United States[1], brook trout (*Salvelinus fontinalis* or EBT) are a primary species of conservation concern. This project, developed by Trout Unlimited and funded by the National Fish and Wildlife Foundation, gathers and interprets existing spatial data related to the pattern of EBT populations, their habitats, and threats to those habitats for identifying needs and opportunities for conservation across the species' eastern range.

This project has three main components – a Conservation Portfolio, Range-wide Assessment, and four focal area assessments - which all use a standard conservation planning approach of summarizing spatial data within a common watershed unit and interpreting the watershed summaries to facilitate comparison and strategic planning at landscape-scales (see Williams et al. 2007).

The *Brook Trout Conservation Portfolio* component characterizes each contiguous EBT population "patch" (Eastern Brook Trout Joint Venture - EBTJV) based on how each existing population contributes to the range-wide diversity of EBT. For three regions (Northeast, Mid-Atlantic, and Southern Appalachian) within the larger EBT distribution (Figure 1), the conservation portfolio evaluates each population for its resiliency to disturbances, likelihood of demographic persistence, and representation of genetic, life history, and geographic diversity. Key data sources include the EBTJV patch characteristics, stream habitat classification data, and stream temperature and EBT probability of occurrence models.

The *Eastern Brook Trout Range-wide Assessment* characterizes EBT population patches and their adjacent subwatersheds (12 digit hydrologic unit code watersheds; NRCS; Figure 3) based on the current pattern of habitat alteration and anticipated threats. Widely-available, range-wide datasets and other EBTJV products provide the foundation for the assessment. The range-wide habitat condition and threats results provide a means to identify generalized conservation strategies – such as restoration or protection - within EBT patches and are intended to provide additional context to the conservation goals established through the portfolio analysis.

The *Eastern Brook Trout Focal Area Assessments* further evaluate habitat condition and future threats within EBT patches using local datasets in four focal geographies: the Upper Chesapeake, Upper Susquehanna, Upper Delaware, and Upper Connecticut basins[2] (Figure 1). The focal area assessments identify existing products to help inform EBT patch characterization, map regional-specific stressors, and integrate additional factors, including ecosystem services, monitoring data, and existing restoration activities, into the range-wide assessment.

Results for all three products are available in a webmap and GIS database format, allowing users to develop custom queries and configurations of the results for identifying specific opportunities or for evaluating projects. A project page is available online at www.tu.org/ebt-portfolio-rwa

[1] The assessment does not cover native brook trout distribution in the upper Midwest (MI, MN, WI) or Canada.
[2] Maine focal area assessment to be completed in late 2017.

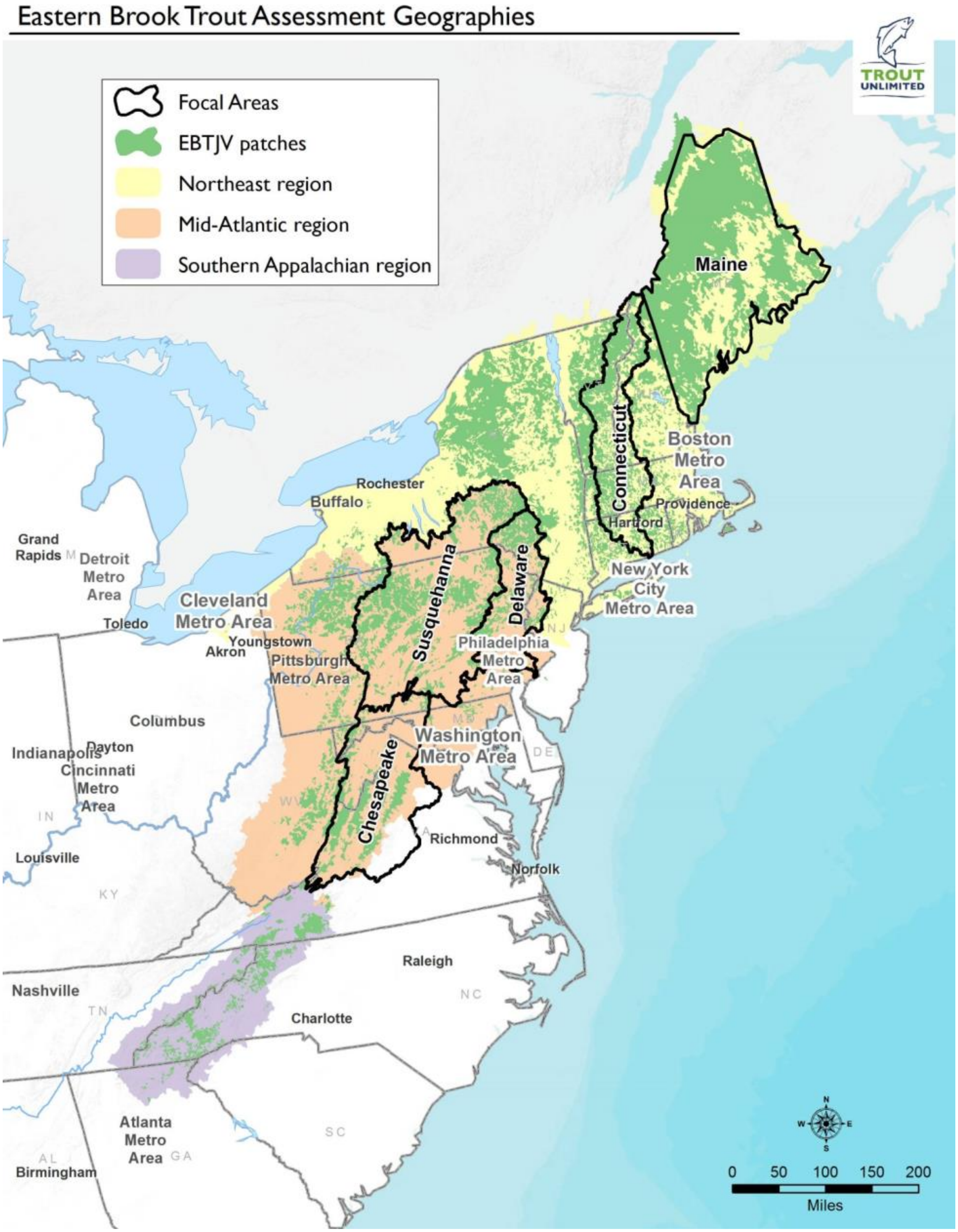

Figure 1: Geographies covered by components of the EBT assessments

Methods: Eastern Brook Trout Conservation Portfolio

The Conservation Portfolio is a framework for defining conservation goals within regions and subregions of EBT distribution. Once population goals are established and the current status of populations mapped, other spatial assessment products, including the range-wide and focal area analyses presented here, can then be used to develop specific, place-based conservation strategies and tactics within EBT patches based on population, habitat, and threat factors. This information can be used to determine priority areas for protection, restoration, and reintroduction in order to achieve the conservation goals established through the portfolio analysis.

The Conservation Portfolio approach is grounded in one of the basic tenets of conservation biology: diversity provides stability. Biologically diverse communities are better able to withstand disturbance and swings in environmental conditions that would destabilize communities dominated by few species or populations. This concept is applicable to entire ecosystems as well as individual species or subspecies. A diverse conservation portfolio for native trout spreads the risk of loss across a variety of habitats and populations through the inclusion of at least some proportion of the life history, habitat and genetic diversity that has allowed these fishes to succeed and persist over time despite disturbances and changes to their environment. The portfolio for native trout exists along a continuum with historical diversity being the most 'balanced' (Figure 2). While it is no longer possible to fully restore historical conditions, conservation strategies that protect and restore multiple examples of these elements of diversity and large patches of interconnected habitat can move the portfolio along the continuum from unbalanced to balanced and reduce the threat of biodiversity loss.

Retains historical genetic, life history, and geographic diversity

- Presence of large inter-connected populations
- Populations occupy a variety of habitats (streams, rivers, lakes)
- All life history forms present historically are represented
- Non-hybridized populations exist in all historically occupied sub-basins

Has lost historical diversity

- Small populations
- Minimal connectivity
- Small stream habitats
- No migratory populations
- Reduced geographic distribution

Figure 2. Continuum of a conservation portfolio for native trout, from unbalanced to balanced.

In order to provide a structure to describe and map existing and potential future levels of diversity within a conservation portfolio, we adopt the 3-R framework of **Representation** (protecting/restoring diversity), **Resilience** (having sufficiently large populations and intact habitats to facilitate recovery from rapid environmental change), and **Redundancy** (saving enough different populations so that some can be lost without jeopardizing the species) (Shaffer and Stein 2000). These same principles have been applied by the US Fish and Wildlife Service in developing recovery plans for listed species (Carroll et al. 2006) and for cutthroat trout subspecies in the western US (Haak and Williams 2012). Table 1 outlines how the 3-R framework can be applied for setting objectives for EBT conservation, and the corresponding indicators of success.

Conservation Goal	Objectives	Indicators of Success
Representation	1. Conservation of genetic diversity 2. Protection and restoration of life history diversity 3. Protection of geographic (ecological) diversity	1a. Presence of genetically unaltered populations 2a. Presence of all life histories that were present historically 3a. Presence of peripheral populations
Resiliency	1. Protect/restore large metapopulations or strongholds	1a. Large brook trout-only populations
Redundancy	1. Protect multiple persistent populations within each subregion	1a Large brook trout-only populations 1b. Moderately sized brook trout-only populations with high habitat suitability 1c. Small brook trout-only populations with exceptional habitat suitability

Table 1. Goals, objectives, and indicators of success in the conservation of EBT.

Previous application of the 3-R framework to cutthroat trout subspecies had the benefit of detailed spatial data related to genetic status, current and historical distribution, observed life history, and population densities, all delineated at the stream reach scale. These data have not been compiled for EBT[3] and in their place we have based the EBT conservation portfolio on the following mapped data:

- EBTJV patch data (EBTJV 2015) map contiguous EBT habitats in the form of a watershed boundary or population “patch” delineated based on presence/absence survey and dams information (Figure 3). Patch attributes applicable to the conservation portfolio include overall size (area) and trout species composition information. We make an assumption that all stream habitats within the patch are occupied and accessible to EBT, and use the EBTJV catchment-scale data to identify EBT-only stream habitats (i.e., allopatric populations that do not compete with brown or rainbow trout) within patches.
- Coastal and anadromous brook trout assessment data (Dauwalter et al. 2014) provides detailed distribution information for the unique EBT sea-run life history.
- National Hydrography Dataset Plus (NHD Plus; EPA and USGS 2005) provides stream size (contributing area) information and the delineated stream network (length) within patches.

[3] A database of EBT genetic information is currently being compiled by USGS (Kazyak and King) and some fish density survey information has been compiled by EBTJV and for this project; however a comprehensive, range-wide dataset is lacking.

- Stream temperature and EBT occurrence probability models (DeWeber and Wagner 2014, DeWeber and Wagner 2015) provide range-wide predictions of maximum 30-day moving average stream temperature and probability of EBT occurrence at the NHD Plus stream reach scale.
- Stream and lake habitat classification datasets (Anderson et al. 2013; Olivero Sheldon et al. 2015) provide mapped lake size information (lake area), modeled stream alkalinity, and modeled lake temperature and trophic state information applicable to the portfolio.
- Maine Heritage Waters and EBT pond datasets provide the locations of lakes and ponds with wild EBT populations with no or limited histories of stocking.

Representation

Representation, as applied to EBT, encompasses three attributes important to diversification of a species' portfolio: life history, geography, and genetic status. Life history diversity is characterized for EBT based on the diversity of habitats accessible to EBT within patches or, in the case of anadromy, observed expression of a particular life history. Our habitat-focused characterization of populations assumes that individuals will develop life histories to exploit available habitats, that larger, more diverse or productive habitats lead to the expression of unique life histories, and that the expression of these unique life histories confers and increases the stability and likelihood of persistence of populations (Rieman and Dunham 2000; Moore et al. 2014). Table 2 describes the various life histories and corresponding criteria applied in the portfolio.

The portfolio's geographic diversity component identifies populations occupying unique ecological regions where evolutionary history may be different than within the core of a species' distribution. These areas may have a longer history of evolutionary isolation and thus support unique traits or adaptations (Haak et al. 2010). They are delineated based on the assumption that small watersheds draining the eastern slopes of the Appalachians or those flowing directly into the Atlantic Ocean or Great Lakes represent unique geographic lineages. The delineation also includes lower tributaries of major drainages where the confluence is outside of the historical range (e.g., Savannah or James Rivers). Drainages originating in the interior of the Appalachians (e.g., Tennessee, Ohio, Potomac, Susquehanna, Delaware, or Connecticut basins) are more representative of core habitat. Additionally, the extent of the Last Glacial Maximum was incorporated into the delineation of the Northeast and Mid-Atlantic regions; regional summaries are presented for all portfolio results in part to reflect different potential EBT lineages across regions.

Data are insufficient for categorizing the genetic status of EBT populations. As data on levels of introgression and origin become available, they may provide additional resolution for characterizing genetic diversity within the portfolio.

Life History	Criteria	Rationale
Migratory – river	Max. stream size class[4] minus min. stream size class ≥ 2 & stream habitat ≥ 25 km OR length-weighted stream size class ≥ 3 & stream habitat ≥ 25 km	Diverse inter-connected stream habitats that include larger systems will support migratory life history
Migratory – lake	Lake size ≥ 0.25 ha & stream habitat ≥ 5 km OR lake size ≥ 5 ha & stream habitat ≥ 1 km	Connected lake and stream habitat of sufficient size will support migratory life history between lake and stream
Migratory – sea run (Northeast only)	Population identified in Dauwalter et al. 2014 as "High, Moderate, or "Low-moderate" certainty of anadromy	Anadromous life history expressed in coastal streams
Resident – more productive	Length-weighted stream size class ≥ 3 & length-weighted alkalinity class[5] > 2	Larger and more alkaline streams are more productive and will support fast-growing and short-lived resident populations
Resident lake/pond (Northeast only)	Ponds or lakes not connected to NHD Plus stream network. Includes ME Heritage Waters or pond or NHD Plus lakes not characterized as "warm" or "hypereutrophic"	Isolated resident brook trout without access to stream habitats
Resident – less productive	All other populations	Small streams or lakes support less unique resident populations

Table 2: Criteria and rationale for life history categories

Resiliency

Resiliency is the capacity for populations to recover from environmental disturbances, and is associated with larger population patches with diverse stream habitats and fewer non-native trout species. Resilient populations are identified in the portfolio based on the presence of strongholds or metapopulations, applying criteria related to stream habitat extent and patch size from Hilderbrand and Kershner (2000). The strongholds must contain a minimum amount of habitat occupied by allopatric EBT populations due to the competitive exclusion of EBT or reduced EBT occurrence when co-occurring with non-native trout, especially brown trout (*Salmo trutta*) (Waters 1983, Wagner et al. 2013, Hitt et al. 2016). To be classified as resilient, an EBT population patch must meet BOTH of the following criteria:

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[4] Stream size classes assigned to each reach based on NHD Plus contributing area. lass 1 (small headwaters): < 5 km²; Class 2 (headwaters): 5-10 km²; Class 3 (small creek): 10 -50 km²; Class 4 (creek): 50 – 100 km²; Class 5 (small river): 100 – 500 km²; Class 6 (river): > 500 km²

[5] Stream alkalinity classes based on The Nature Conservancy's Northeast Aquatic Habitat Classification for EBT Northeast and Mid-Atlantic regions and Stream Classification for the Appalachian Region for EBT Southeast region as follows: Class 1: (NE "Low (< 25 mg/L)"; App. "Low buffered, acidic"); Class 2: (NE "Medium (25 - 50 mg/L)"; App. "Moderately buffered, neutral and Assumed moderately buffered "); Class 3: (NE "High (50 – 150 mg/L) and Very high (≥ 150 mg/L:)"; App. "Highly buffered, calcareous");

- Include at least 25 km or 25km² of brook trout-only (allopatric) stream habitat[6] – these patches have ample stream habitat where brook trout occur without competition with non-native trout and meet minimum stream length criteria required for long-term viability[7].
- Include a Class 4 stream (a stream with at least 50 km² contributing area) – these patches include diverse habitats which supporting different life history strategies in EBT and allow for recovery following disturbance.

Populations with these characteristics also meet the criteria for migratory – river life history identified in the representation portion of the portfolio analysis.

Redundancy

Redundancy relates to the occurrence of multiple populations that can be considered persistent, or having the demographic capacity to resist genetic bottlenecks through sufficient population size. Redundancy provides a spatial hedge against losses by securing multiple populations within each sub-region of the historical range. In order for a population to count towards redundancy it must satisfy criteria related to the amount of occupied habitat, suitability of habitats – as a proxy for observed abundance and density information applied in other conservation portfolio applications – and the presence of non-native trout species. EBT habitat suitability is based on DeWeber and Wagner (2015) models which predict occurrence probability based on landscape attributes (soil permeability, agricultural and developed land cover, and modeled stream temperature). The stream temperature model is constructed using air temperature, landform factors (aspect, catchment area, groundwater contributions), and forest cover at the riparian and watershed scale (DeWeber and Wagner 2014). We assume that higher occurrence probabilities equate to higher habitat suitability; within 2007 EBTJV subwatershed assessment data, mean probability of EBT occurrence is highest in intact populations (0.57) vs. greatly reduced (0.37) or extirpated populations (0.22) (DeWeber and Wagner 2015). To be classified as redundant, an EBT patch must meet ONE of the following criteria:

- Include at least 25 km or km² of brook trout-only (allopatric) stream habitat[8] – these large patches have ample stream habitat where brook trout occur without competition with non-native trout and meet minimum stream length criteria required for long-term viability (Hilderbrand and Kershner 2000). These patches also meet resiliency criteria.
- Include between 5 and 25 km or km² of brook trout-only (allopatric) stream habitat[8] and have patch-average occurrence probabilities exceeding 0.3 – these moderately sized patches have high habitat suitability.

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[6] In the Mid-Atlantic and Southern Appalachian regions, the 25km threshold is used; in the Northeast region, the 25km² threshold is used. Criteria differ by region reflecting importance of lake habitat in Northeast region.

[7] Hilderbrand and Kershner (2000) estimate a 25km minimum stream length is required for low abundance populations (0.1 fish/m) to maintain an effective population size of 500 in interior cutthroat trout – we use this cutoff.

[8] In the Mid-Atlantic and Southern Appalachian regions, the linear km threshold is used; in the Northeast region, the areal km² threshold is used. Criteria differ by region reflecting importance of lake habitat in Northeast region.

- Include less than 5 km or km² of brook trout-only stream habitat[8], but at least 10 km of all stream habitat, and have patch-average occurrence probabilities exceeding 0.5 – these small patches have very high habitat suitability.

Methods: Eastern Brook Trout Range-wide Conditions and Threats

The EBT Range-wide Assessment is a compilation and assessment of spatial information related to the integrity of freshwater habitats and anticipated future threats to coldwater habitats across the full historical distribution of EBT in the eastern US. The analysis is completed for 2 separate spatial scales: within EBT population patches (the spatial scale of the Portfolio analysis) and within the portions of surrounding or neighboring subwatersheds (12 digit hydrologic unit code watersheds or HUC12; NRCS) unoccupied by EBT (Figure 3). For each scale, the assessment summarizes spatial (GIS) data related to a broad suite of anthropogenic stressors and environmental factors. Each data summary is then converted to a percentile score reflecting the rank of the assessment unit along the continuum of condition or vulnerability within common units (i.e., among EBT patches or among unoccupied subwatershed areas)[9]. This watershed data "summary and scoring" approach is a standard conservation planning tool and is similar to products developed by other land management agencies and conservation partners, including TU's Conservation Success Index (Williams et al. 2007), the Watershed Condition Framework developed by the US Forest Service, and the NFHAP Data System created by the National Fish Habitat Partnership.

We evaluate the habitat integrity and vulnerability factors for correlations within the EBT patch summaries, for data quality, and for relevance across the full extent of the analysis. We identify a set of uncorrelated, high quality "primary" factors applicable for the full range of EBT for describing habitat condition and future security within assessment units. These factor scores are averaged to report a composite rank. The remaining "secondary" factors are retained for reference. The composite rank and percentile scores for individual factors provide additional context to the portfolio analysis and are interpreted to generalized conservation strategies for each population, while the summaries for subwatersheds provide context for adjacent habitats and are interpreted for their suitability as expansion or reintroduction habitat for EBT. As an additional consideration for reintroduction or expansion strategies, we also summarize the area occupied by wild trout (naturally reproducing rainbow or brown trout; EBTJV 2015) for unoccupied subwatershed areas only. Data sources for each factor are listed in Appendix 1; EPA's StreamCat database (Hill et al. 2016) serves as a key source.

Habitat Integrity

The current condition of aquatic habitats is characterized in the Range-wide Assessment for four themes of factors:

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[9] As an example of how the scoring process works, take a population and adjacent unoccupied subwatershed, both with 12% agricultural land use. For the population, 12% agricultural land use yields a percentile score of 41% among populations for that factor – 59% of populations have a smaller proportion of agricultural land use. For the subwatershed, 12% agricultural land use yields a percentile score of 64% among subwatersheds for that factor – 36% of subwatersheds have a smaller proportion of agricultural land use. Thus, the percentile score is a means to compare within groups.

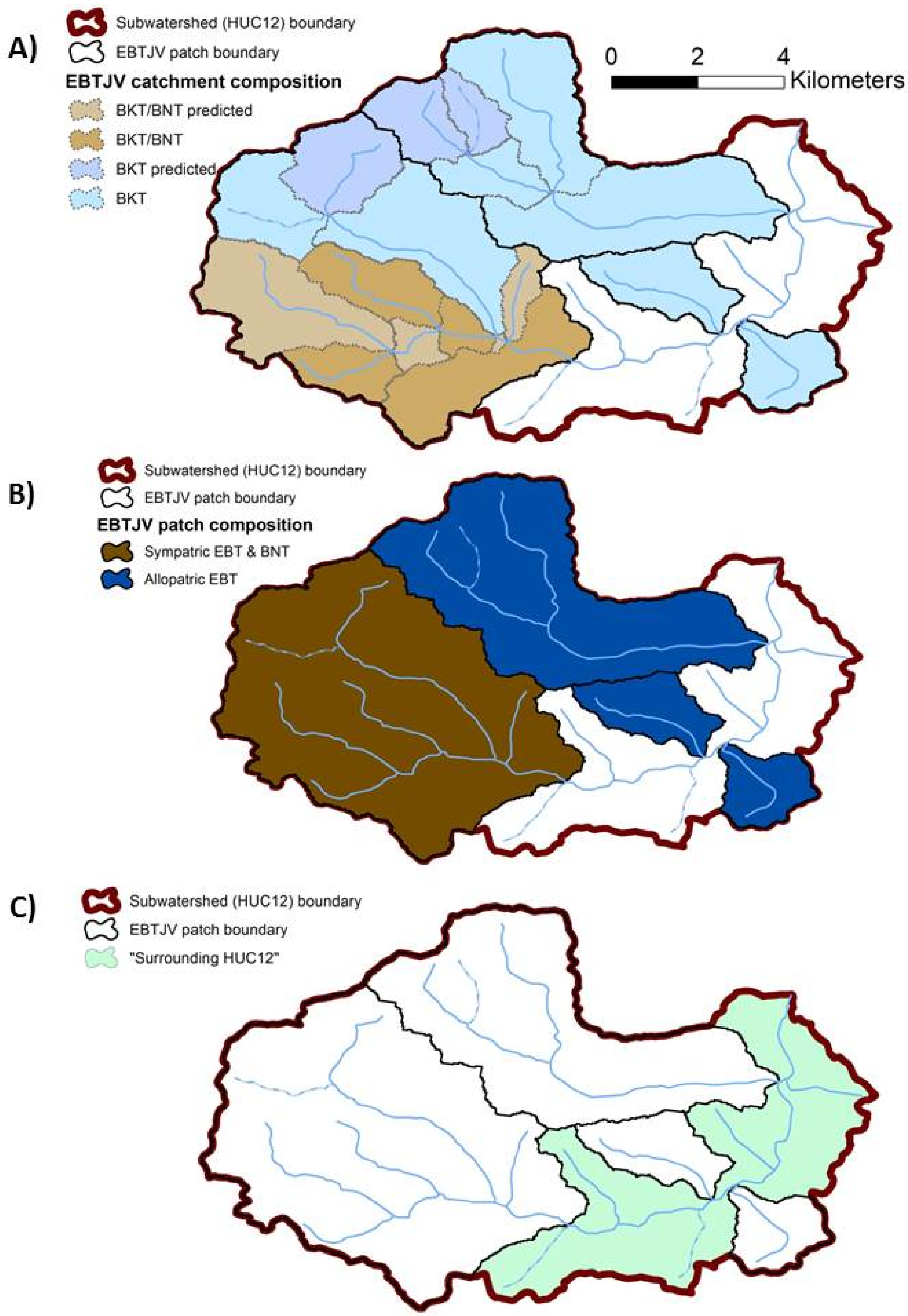

Figure 3: Examples of A) catchment, B) patch, and C) portions of subwatershed summary units "surrounding" the patches which are currently unoccupied by EBT.

- *Land Use* factors relate to land cover within patches and riparian zones and include summaries of the percent of watershed forested, percent of riparian zone forested, percent of watershed with agricultural land use, percent impervious surface, and road density within assessment units. Research links higher likelihood of brook trout occurrence with higher percent forested watershed and riparian cover, lower agricultural land use, and lower road densities and percent impervious surfaces – critical thresholds for EBT occurrence include at least 68 - 75% forested land cover (Hudy et al. 2008, Stranko et al. 2008, Kanno et al. 2015), less than 2.5 to 25% agricultural land use (Wagner and Midway 2014, DeWeber and Wagner 2015, Hudy et al. 2008),greater than 80% forested riparian cover (Ecosheds 2016), road densities less than 3.2 miles/mile^2 (Hudy et al. 2008), and less than 4% impervious cover (Stranko et al. 2008).
- *Habitat Fragmentation* factors account for the likely connectivity of habitats within patches, as influenced by road culverts, by summarizing the density of road-stream crossings in the population patch or subwatershed. This factor serves as a proxy for a broadly available fish passage dataset, which does not exist for the eastern range of brook trout.
- *Flow Regime* factors quantify dams and their storage capacity in each habitat patch or subwatershed. Natural flow regimes are critical to proper aquatic ecosystem function (Poff et al. 1997) and dams and reservoirs alter flow regimes (Benke 1990).
- *Water Quality* factors includes information related to current and legacy energy development, including the number of active mines, active conventional or unconventional (shale) oil and gas wells, amount of atmospheric acid deposition, and miles of stream identified on the 303d list for impairment for any reason. Energy development can cause aquatic habitat degradation from the potential for spills and direct discharge of fracking fluids or produced water and fragmentation effects from service roads, pipelines, and water withdrawals (Entrekin et al. 2011, Weltman-Fahs and Taylor 2013). Chronic and acute exposure to acidified water has been linked to mortality and stress in EBT (MacAvoy and Bulger 1995).

Future Security

Anticipated threats to aquatic habitats are characterized in the Range-wide Assessment for four themes of factors:

- *Resource Development* factor accounts for the likely locations of gas and coal resource development in the Central Appalachians (Dunscomb et al. 2014) to characterize the risk of energy development within patches or subwatersheds.
- *Urban Development* factor summarizes the relative risk of development of private land into urban, suburban and exurban land use in 2030 (Theobald 2005).
- *Climate* includes two factors assessing the vulnerability of aquatic habitats to climate change: modeled stream temperatures and presence of Karst geology types. Stream temperature has a strong negative relationship with EBT occurrence and interacts with other land use effects to amplify their impact (DeWeber and Wagner 2015); karst features can be important sources of cool groundwater typically not accounted for in stream temperature models, and indicate a higher buffering ability against acidic inputs (Sharpe et al. 1987).

- *Land Stewardship* factor summarizes the percentage of each patch or subwatershed with lands in a protected status. Stream habitats and watersheds with higher portions of lands in federal, state, or private conservation ownership are likely to experience less anthropogenic disturbance than other land or offer a means to influence land use decisions through public participatory processes.

Methods: Focal Area Assessments

The focal area assessment adds additional resolution to the portfolio and range-wide assessment components by summarizing two categories of additional spatial data – focal area-specific datasets and regional products. Focal area-specific datasets provide similar information as addressed in the range-wide assessment such as habitat condition and threats factors, but at a finer spatial resolution or more recent temporal resolution, or address a focal area-specific condition or threat not addressed in the range-wide assessment. For example, the Chesapeake, Susquehanna, and Delaware focal area assessments include summaries of datasets related to the occurrence and impact of abandoned mine drainage on aquatic habitats. The focal area assessments also include key regional EBT datasets available for all or individual focal areas, but not for the full range of EBT in the eastern US. Regional datasets include:

- EBT occupancy and stream temperature models produced by as part of the Spatial Hydro-Ecological Decision System project (Ecosheds 2016).
- EBT occupancy models and habitat quality and total stress indices produced by Downstream Strategies in the Chesapeake Bay (Clingerman et al. 2015).
- Regional conservation priorities, including Delaware River Basin Initiative (The Nature Conservancy 2011) and Connect the Connecticut (North Atlantic Landscape Conservation Cooperative 2016).
- State-specific designations, including exceptional waters and trout water designations.
- Regional tools, including the Riparian Restoration Decision Support Tool (Coombs and Nislow 2014).
- Thematic additions, such as the Forests to Faucets drinking water source data (Weidner and Todd 2009).

A full list of datasets summarized by EBT population patch is provided in Appendix 2.

Results: Eastern Brook Trout Conservation Portfolio

Tables 3, 4, and 5 and Figures 4, 5, and 6 summarize and map EBT conservation portfolio results by region and subregion. Mapped results are best explored using the accompanying web-based map viewer.

EBT occur in 5,543 patches covering over 12 million hectares in the Northeast Region. Fifty-seven percent of patches host allopatric EBT populations. The patches have an average size of approximately 2,250 ha and are 55% of the total number of EBT patches within the assessment area, and 66% of the

Subregion	Patch Size (Ha) Total	Patch Size (Ha) Ave.	Populations All	Populations Allo-patric	Representation Geo. Div.	Life History Diversity Mig-Lake	Mig-River	Mig-R&L	Mig-Sea	Res-↑Prod	Res-↓Prod	Res-Pond	No Data	Resilient Strong-hold pops.	Redundant Persistent pops.
Cape Cod	164,410	694	237	213	91	1	3	0	16	0	204	2	11	5	60
Saco-Merrimack	897,080	1,400	641	601	145	112	14	35	1	0	441	33	5	37	310
Total Coastal RI/MA/NH	1,061,490	-	878	814	236	113	17	35	17	0	645	35	16	42	370
Connecticut River	1,547,743	1,540	1,005	698	73	60	50	34	0	16	810	28	7	68	480
Total Connecticut River	1,547,743	-	1,005	698	73	60	50	34	0	16	810	28	7	68	480
Hudson River	1,152,275	1,419	812	385	0	75	24	17	0	18	615	50	13	23	236
Long Island Sound	515,502	863	597	380	149	17	13	2	7	1	530	7	20	8	130
Total Hudson/L.I. Sound	1,667,777	-	1,409	765	149	92	37	19	7	19	1145	57	33	31	366
Coastal Maine	761,195	3,368	226	226	147	63	6	23	16	0	90	20	8	37	150
Interior Maine	3,041,108	6,058	502	491	45	137	10	84	1	2	224	40	4	112	360
Northern Maine	1,783,679	17,660	101	100	0	23	4	28	0	1	26	7	12	37	68
Total Maine	5,585,982	-	829	817	192	223	20	135	17	3	340	67	24	186	578
Great Lakes	806,412	1,133	712	164	712	56	22	26	0	21	558	12	17	20	160
Saint Lawrence	1,769,823	2,493	710	249	0	125	38	53	0	14	409	66	5	54	303
Total St. Lawrence	2,576,234	-	1,422	413	712	181	60	79	0	35	967	78	22	74	463

Table 3: Summary of Conservation Portfolio results for EBT in the Northeast Region

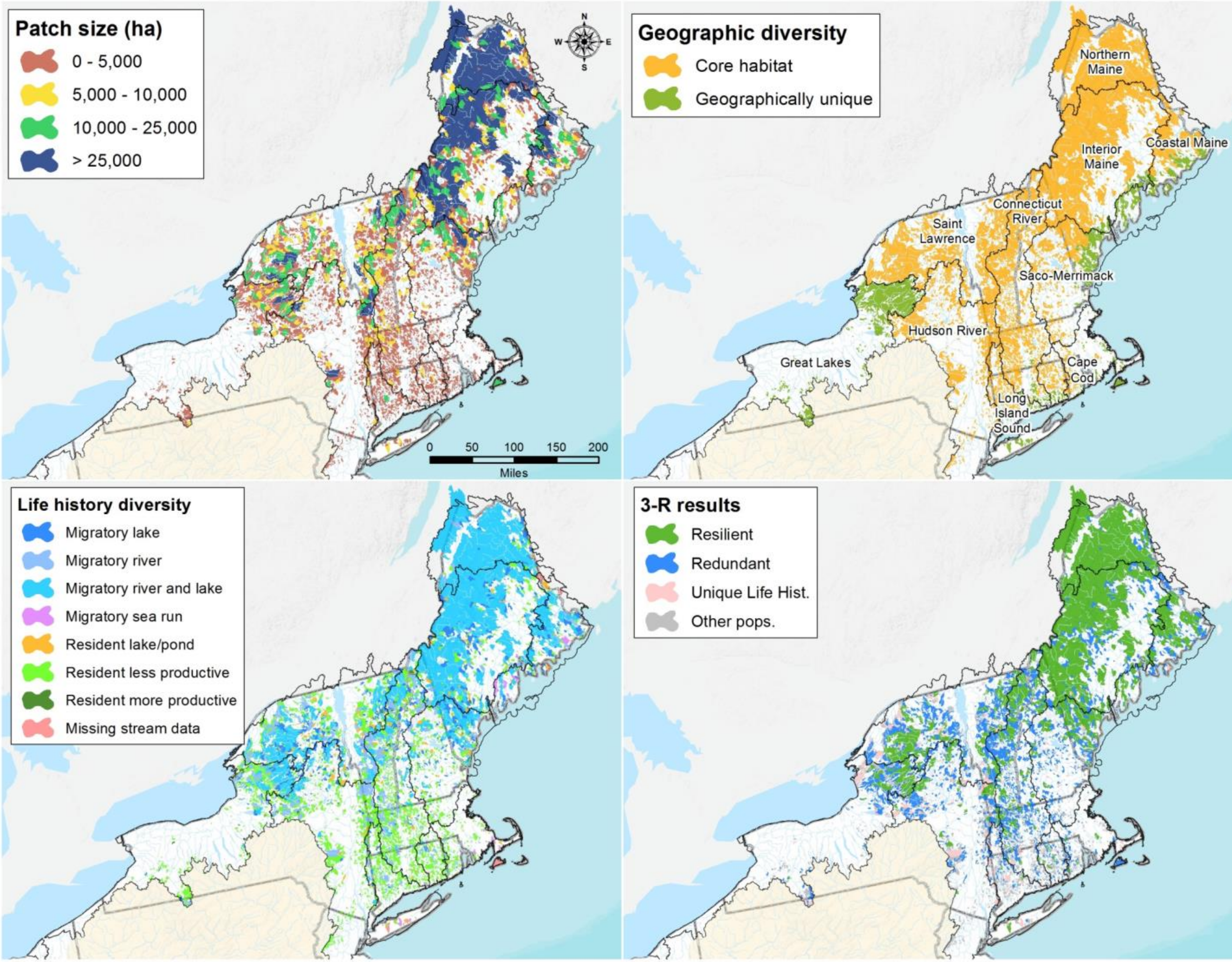

Figure 4: Conservation Portfolio results for EBT in the Northeast Region. Mapped results are best explored through the web-based map viewer

Subregion	Patch Size (Ha) Total	Patch Size (Ha) Ave.	Populations All	Populations Allo-patric	Representation Geo. Div.	Representation Life History Diversity Mig-Lake	Mig-River	Mig-R&L	Mig-Sea	Res-↑Prod	Res-↓Prod	Res-Pond	No Data	Resilient Strong-hold pops.	Redundant Persistent pops.
Chesapeake Bay	33,145	625	53	26	53	2	0	0	0	0	51	0	0	0	0
Lower James	58,462	2,016	29	23	18	1	3	0	0	0	25	0	0	3	3
Lower Potomac	13,776	861	16	11	0	0	0	0	0	0	15	0	1	0	0
Rappahannock	62,283	3,664	17	14	17	0	2	0	0	0	15	0	0	1	1
Upper James	268,896	2,513	107	90	0	1	15	3	0	0	86	0	2	10	54
Upper Potomac	500,244	2,084	240	204	0	15	22	1	0	3	197	0	2	11	102
Total Chesapeake	936,805	-	462	368	88	19	42	4	0	3	389	0	5	25	160
Lower Delaware	258,300	1,435	180	73	74	6	7	4	0	1	156	0	6	3	16
Upper Delaware	470,207	1,532	307	85	0	20	5	6	0	0	273	0	3	1	58
Total Delaware	728,506	-	487	158	74	26	12	10	0	1	429	0	9	4	74
New River	164,522	1,891	87	57	0	0	9	0	0	0	78	0	0	5	43
So. Allegheny Plat.	52,557	2,285	23	13	0	0	5	1	0	0	17	0	0	0	17
Total New	217,079	-	110	70	0	0	14	1	0	0	95	0	0	5	60
Allegheny	828,159	1,416	585	290	0	14	37	5	0	0	526	0	3	12	218
Monongahela	350,812	1,240	283	211	0	2	17	2	0	0	259	0	3	4	139
Ohio - glaciated	2,129	426	5	0	0	0	0	0	0	0	5	0	0	0	0
Total Ohio	1,181,100	-	873	501	0	16	54	7	0	0	790	0	6	16	357
Upper Roanoke	40,831	1,408	29	17	29	0	5	2	0	0	21	0	1	0	9
Total Roanoke	40,831	-	29	17	29	0	5	2	0	0	21	0	1	0	9
Low. Susquehanna	41,361	1,253	33	17	0	0	2	0	0	0	29	0	2	0	0
Mid. Susquehanna	560,862	1,934	290	104	0	11	25	7	0	3	243	0	1	8	53
Up. Susquehanna	801,153	1,833	437	251	0	10	39	17	0	8	357	0	6	25	123
West Branch Susquehanna River	984,563	2,018	488	249	0	5	56	8	0	0	419	0	0	19	238
Total Susquehanna	2,387,940	-	1,248	621	0	26	122	32	0	11	1048	0	9	52	414

Table 4: Summary of Conservation Portfolio results for EBT in the Mid-Atlantic Region

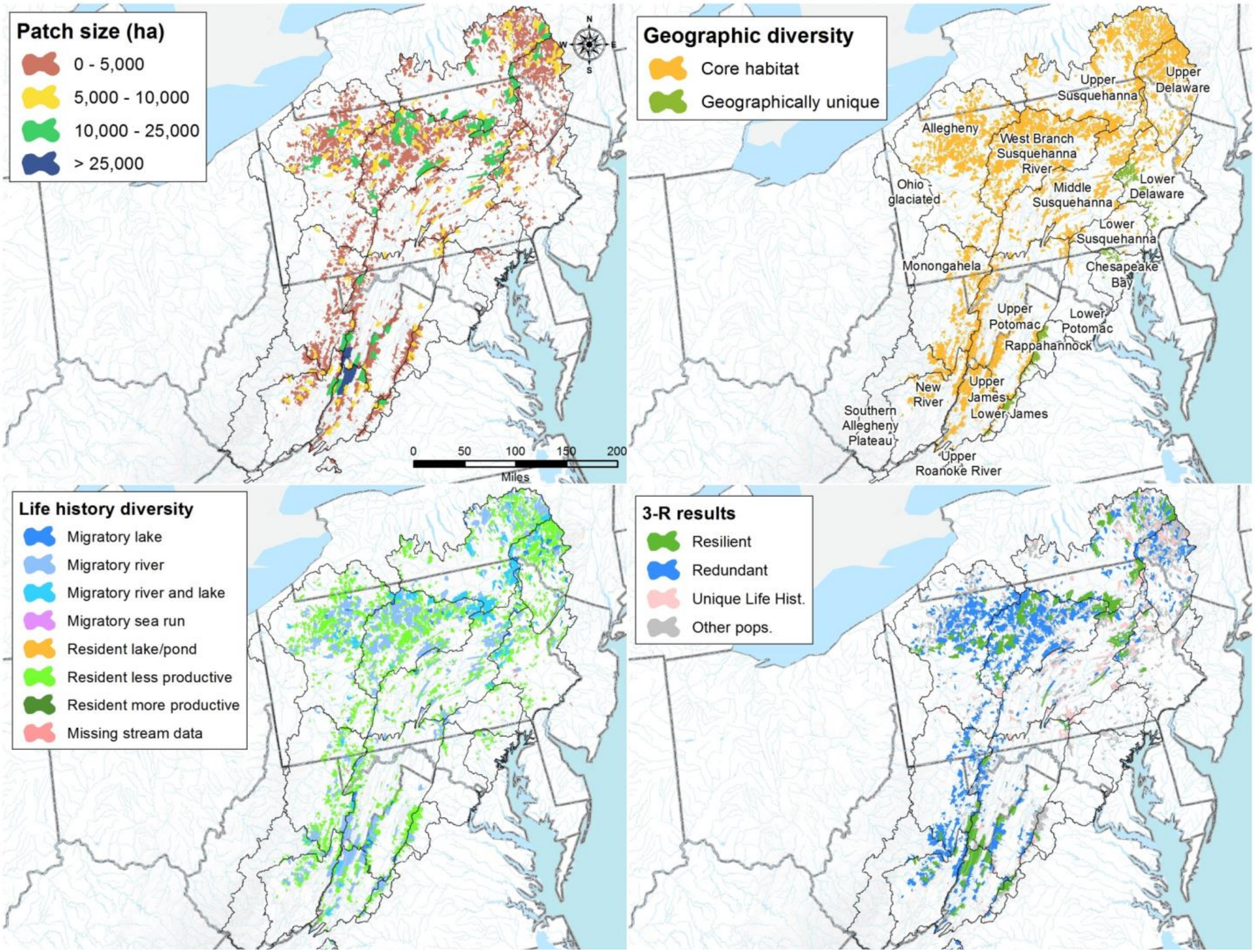

Figure 4: Conservation Portfolio results for EBT in the Mid-Atlantic Region. Mapped results are best explored through the web-based map viewer.

Subregion	Patch Size (Ha) Total	Patch Size (Ha) Ave.	Populations All	Populations Allo-patric	Representation: Geo. Div.	Life History Diversity: Mig-Lake	Mig-River	Mig-R&L	Mig-Sea	Res-↑Prod	Res-↓Prod	Res-Pond	No Data	Resilient: Strong-hold pops.	Redundant: Persistent pops.
Upper Pee Dee River	51,139	947	54	33	54	1	3	2	0	0	48	0	0	1	22
Upper Roanoke River	40,831	1,408	29	17	29	0	5	2	0	0	21	0	1	0	9
Upper Santee River	52,056	505	103	89	103	1	0	2	0	0	100	0	0	1	20
Upper Savannah River	42,126	520	81	59	81	7	0	0	0	0	74	0	0	0	5
Total Atlantic Coastal	186,152	-	267	198	267	9	8	6	0	0	243	0	1	2	56
Apalachicola River-Piedmont	5,540	396	14	12	14	0	0	0	0	0	14	0	0	0	1
Coosa River	3,770	1,885	2	1	2	0	0	1	0	0	1	0	0	0	1
Total Gulf Coastal	9,310	-	16	13	16	0	0	1	0	0	15	0	0	0	2
Hiwassee - Ocoee	22,661	420	54	50	0	0	0	0	0	0	53	0	1	0	7
Tennessee River-Blue Ridge	411,029	580	709	501	0	17	15	6	0	6	653	0	12	7	131
Tennessee River-Ridge and Valley	41,103	913	45	27	0	2	2	0	0	1	40	0	0	0	16
Total Tennessee River	474,793	-	808	578	0	19	17	6	0	7	746	0	13	7	154
Upper New River	296,673	2,018	147	86	0	6	5	11	0	0	123	0	2	12	41
Total Upper New	296,673	-	147	86	0	6	5	11	0	0	123	0	2	12	41

Table 5: Summary of Conservation Portfolio results for EBT in the Southern Appalachian Region

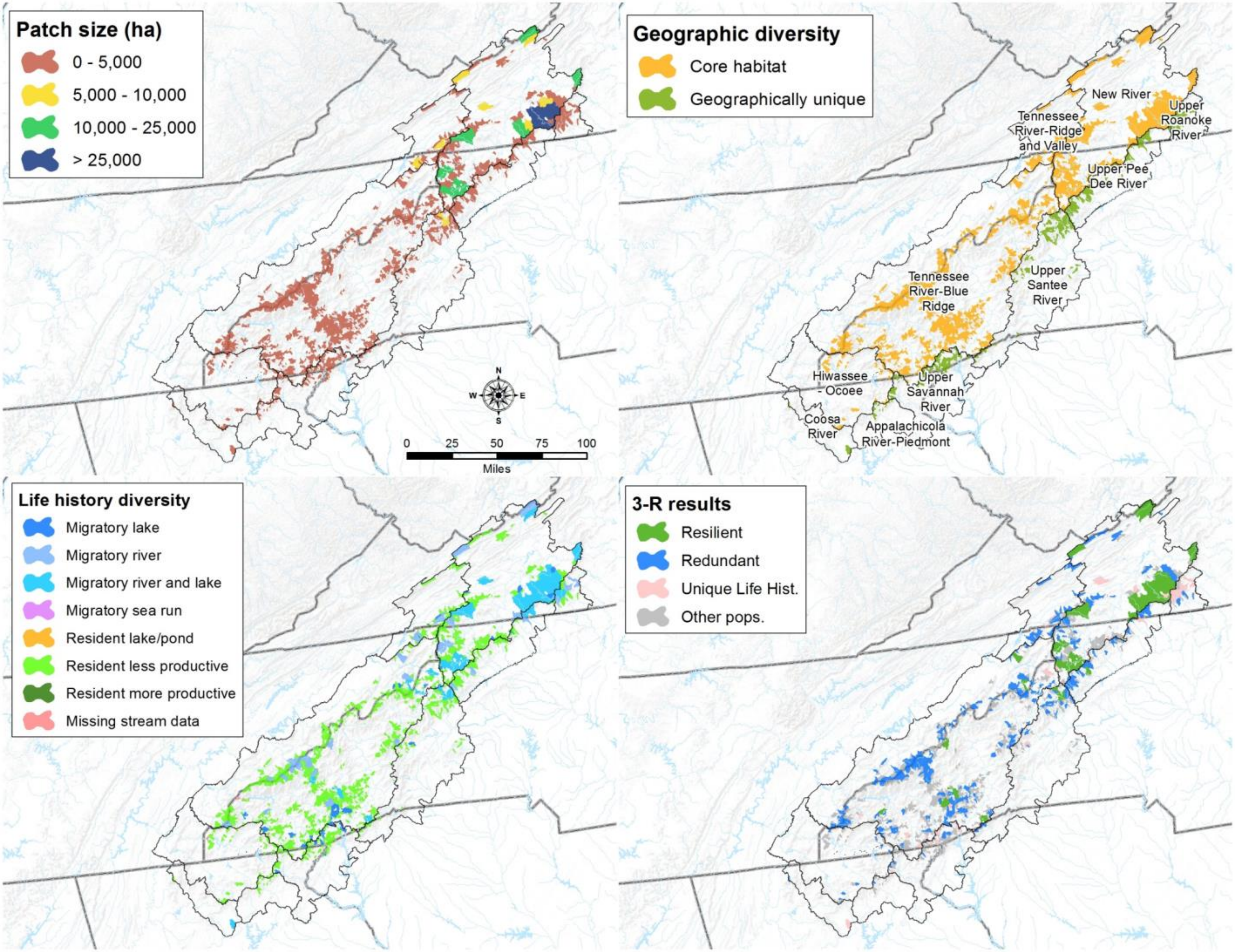

Figure 6: Conservation Portfolio results for EBT in the So. Appalachian Region. Mapped results are best explored through the web-based map viewer.

total patch area. Twenty-five percent of Northeast Region patches are identified as representing a unique geographic diversity, including all patches in the Great Lakes subregion, and representing 75% of geographically diverse population patches across regions. The Northeast is truly the hot spot for diverse EBT life histories - 28% of patches are estimated to have a unique life history based on habitat diversity (i.e., not resident less productive populations). Populations with an observed sea-run life history occur in only 1% of the patches in the region, but these represent 100% of the populations exhibiting anadromy across regions. Also across regions, patches in the Northeast represent 85% of lake, 40% of river, and 79% of combined lake and river life histories. Among highly productive resident populations across regions, 77% occur in the region. Seven percent of patches in the Northeast Region are resilient, and 41% are redundant; these represent 77% of resilient and 63% of redundant patches across regions. Nearly one-in-three patches in the Northern Maine subregion is identified as resilient.

In the Mid-Atlantic Region, 3,194 EBT patches occur in a watershed area totaling over 5 million hectares. These patches represent 32% of the total number of EBT patches in the assessment area and have an average size of roughly 1,700 ha. Allopatric EBT populations occur in 28% of patches. Only 6% of Mid-Atlantic patches – including all those in the Rappahannock and Upper Roanoke basins - are identified as having geographic diversity. Eight percent of patches in the region are identified as having a river migratory life history – those represent over half of the total number of river migratory populations across regions. Fifteen populations are identified as a having a resident, more productive life history, or 16% of the total populations with that strategy for the assessment area. Three percent of populations in the region are identified as resilient or 19% of the total across regions; the greatest numbers of resilient patches are in the Upper Susquehanna and West Branch Susquehanna basins (71 across basins). Thirty-four percent of populations are identified as redundant or 30% of the total across regions.

Nearly 1 million hectares of EBT habitats occur in 1,224 patches in the Southern Appalachian Region. These patches are equal to 12% of the total number of EBT patches in the assessment area, but only 5% of the total area, reflecting the relatively small size of patches in the region (average size is approximately 800 ha). Fourteen percent of populations are allopatric EBT. Twenty-two percent of patches in the region occur outside of the Tennessee and Ohio River systems and are identified for geographic diversity. The vast majority of populations – 91% - have a less productive, resident life history. Only 2% of patches are identified as resilient and 20% are identified as redundant. Across all regions, these represent 4% of the total resilient patches and 7% of the total redundant patches. The greatest numbers of resilient patches in the region are found in the New River basin (12 populations).

Results: Brook Trout Range-wide Conditions and Threats

We selected percent agricultural land use, percent riparian forest, road density, road-stream crossing density, and acid deposition as primary factors for habitat condition and calculated a composite score based on the average percentile score for these factors. We selected stream temperature as the sole primary factor for future security. All other factors are considered secondary due to patch-scale correlation of factors (e.g., percent forested with percent riparian forest; percent impervious surface with road density), data quality (e.g., 303d listing varies in quality and frequency of designation by state), or the relevance of a factor to a limited portion of the larger EBT distribution (e.g., oil and gas

	Subregion	Rip.For	Ag.	Str Xing	Rd Den.	Acid Dep.	Comp	Str. temp.
				Habitat Integrity				**Future Sec.**
Northeast region	Cape Cod	0.31	1.00	0.44	0.20	0.59	0.51	0.24
	Saco-Merrimack	0.46	1.00	0.47	0.38	0.83	0.63	0.55
	Connecticut R.	0.50	1.00	0.48	0.42	0.73	0.63	0.51
	Hudson R.	0.48	0.62	0.60	0.54	0.49	0.55	0.42
	LI Sound	0.36	0.99	0.40	0.23	0.51	0.50	0.30
	Coastal ME	0.49	1.00	0.73	0.59	0.91	0.74	0.61
	Interior ME	0.53	1.00	0.84	0.72	0.96	0.81	0.67
	No. ME	0.45	1.00	0.91	0.77	0.97	0.82	0.77
	Great Lakes	0.30	0.49	0.66	0.54	0.31	0.46	0.46
	St. Lawrence	0.57	0.72	0.73	0.67	0.54	0.65	0.56
Mid-Atlantic region	Chesapeake Bay	0.12	0.24	0.51	0.12	0.17	0.23	0.15
	L. James	0.67	0.74	0.46	0.46	0.32	0.53	0.18
	L. Potomac	0.54	0.66	0.54	0.38	0.23	0.47	0.20
	Rappahannock	0.50	0.46	0.74	0.53	0.66	0.58	0.10
	U. James	0.69	0.73	0.61	0.51	0.26	0.56	0.31
	U. Potomac	0.57	0.58	0.69	0.52	0.27	0.53	0.36
	L. Delaware	0.33	0.51	0.49	0.29	0.23	0.37	0.21
	U. Delaware	0.59	0.65	0.57	0.52	0.45	0.56	0.52
	New R.	0.75	0.91	0.84	0.59	0.21	0.66	0.83
	So. Allegheny Plat.	0.83	0.90	0.83	0.61	0.19	0.67	0.80
	Allegheny	0.51	0.63	0.71	0.55	0.06	0.49	0.68
	Monongahela	0.59	0.66	0.64	0.51	0.15	0.51	0.65
	Ohio - glaciated	0.16	0.27	0.26	0.23	0.01	0.19	0.29
	U. Roanoke R.	0.48	0.51	0.42	0.38	0.30	0.42	0.24
	L. Susquehanna	0.15	0.21	0.39	0.21	0.16	0.22	0.13
	M. Susquehanna	0.49	0.59	0.53	0.41	0.15	0.44	0.32
	U. Susquehanna	0.26	0.28	0.52	0.52	0.29	0.37	0.49
	W.B. Susquehanna R.	0.62	0.71	0.75	0.61	0.07	0.55	0.59
Southern Appalachian region	U. Pee Dee R.	0.66	0.69	0.64	0.53	0.42	0.59	0.56
	U. Roanoke R.	0.48	0.51	0.42	0.38	0.30	0.42	0.24
	U. Santee R.	0.75	0.80	0.66	0.66	0.74	0.72	0.69
	U. Savannah R.	0.78	0.90	0.74	0.62	0.87	0.78	0.48
	Apalachicola R.-Piedmont	0.91	0.99	0.93	0.83	0.83	0.90	0.39
	Coosa R.	0.63	0.76	0.67	0.57	0.67	0.66	0.17
	Hiwassee - Ocoee	0.82	0.92	0.65	0.72	0.80	0.78	0.35
	TN R.-Blue Ridge	0.75	0.84	0.65	0.62	0.78	0.73	0.53
	TN R.-Ridge & Valley	0.71	0.70	0.49	0.61	0.44	0.59	0.56
	U. New R.	0.43	0.44	0.50	0.41	0.41	0.44	0.53

Table 6: Average primary Habitat Integrity and Future Security factor percentile scores by subregion.

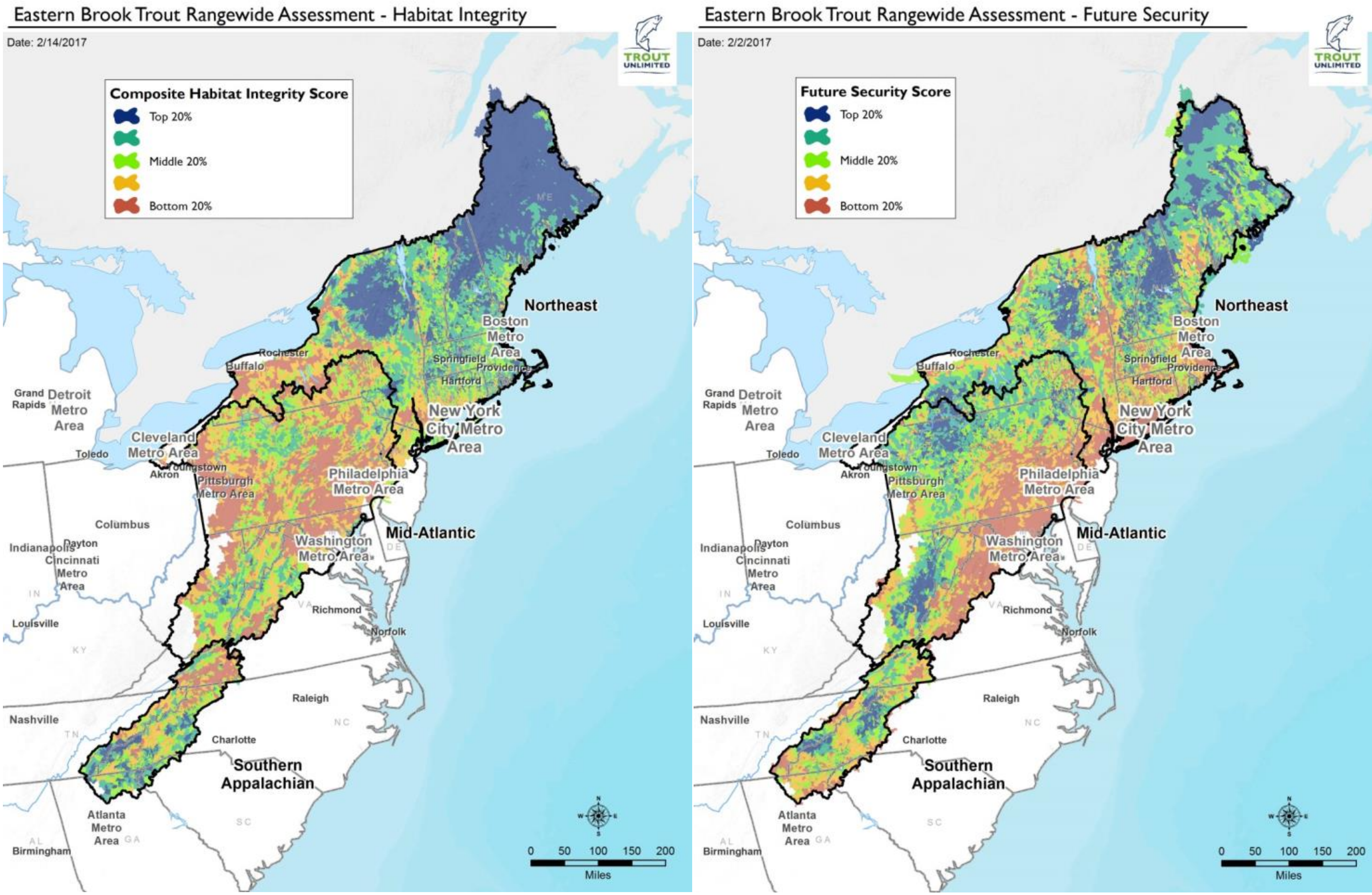

Figure 7: Range-wide habitat integrity and future security average categorical scores for EBT patches and surrounding and adjacent subwatersheds.

wells are largely limited to the Central Appalachian region). Details on the rationale for primary/secondary factor categorization are provided in Appendix 1. Table 6 summarizes EBT range-wide assessment results for the primary habitat integrity and future security factors by subregion for EBT population patches. Figure 7 maps composite habitat integrity and future security scores across the full geography of the assessment area for patches and surrounding and adjacent subwatersheds; mapped results are best explored using the accompanying web-based map viewer.

For primary habitat condition factors, the pattern of several land use-related factors is correlated at the subregional scale – percent riparian forested, road density, and road-stream crossing scores across subregions tend to have similar, even distributions, reflecting the broad and widespread distribution of the stressors across the range of EBT in the East. The exceptions are subregions with large federal land base which includes formal protected status as national park or wilderness areas (e.g., Chattahoochee-Oconee National Forest in the Apalachicola River – Piedmont subregion). Percent agricultural land use scores have a less even distribution across and within subregions, with lower scores in lower elevation portions of EBT distribution (e.g., Chesapeake Bay and Lower Susquehanna subregions). Acid deposition is most acute as a stressor within the central portion of EBT distribution, as evidenced by lower subregional scores in the Mid-Atlantic region (Table 6). Large blocks of EBT population patches with high composite habitat condition occur in Maine, White Mountains of NH, Adirondack Mountains of NY, and the southern Blue Ridge Mountains (Figure 7). For the stream temperature factor, the pattern of patch and subwatershed percentile scores tracks closely with elevation and, to a lesser degree, latitude – highest scores are found in the highest elevation portions of EBT distribution within regions, including the Smoky and Black Mountains of NC, Highlands of WV, Allegheny Mountains of PA and NY, Adirondack Mountains of NY, White Mountains of NH, and northern ME (Table 6, Figure 7).

Results and Discussion: Conservation Strategies based on Portfolio and Range-wide Assessment

The combined portfolio and range-wide assessment results provide a characterization of EBT populations, habitats, and threats from multiple data sources summarized at a common spatial scale. We identify where each EBT population patch or adjacent subwatershed falls within the continuum of viability, condition, and vulnerability for EBT in the Eastern US. By juxtaposing portfolio results for patches against the composite habitat condition score, we identify generalized conservation strategies for each EBT population (Figure 8). Habitat integrity score provides a generalized sense of the magnitude of habitat restoration need for each population. Populations with high integrity (composite scores > 0.7[10]) are on average among the top 30% least disturbed EBT populations and likely lack acute stressors. These populations represent opportunities to address restoration needs of low complexity. Portfolio results reflect the likelihood of long-term population viability given the type and amount of habitat available to populations. While the scope of habitat restoration activities is likely greatest in resilient

[10] Individual habitat condition factor percentile scores of 70 for agricultural land use, riparian forest cover, and road density are below thresholds associated with decreasing probability of EBT occurrence – see Methods section for discussion of critical thresholds. At the 70th percentile score level, agricultural land use = 8%, riparian forest = 90% and road density = 2.6 miles/mile².

populations – those largest connected habitat patches – the scale of impact or lasting benefit of restoration for those populations is also high.

Rangewide EBT conservation strategy categories are as follows.

- *Secure strongholds* strategy is assigned to resilient patches with high habitat integrity (2.6% of existing EBT populations). These patches meet our criteria as strongholds and have relatively few stressors present. Due of overlap in the portfolio categories, these patches also meet redundancy criteria and contain migratory river populations. This category represents an objective – ideally all patches would be in this category, with large interconnected habitats with few acute stressors. Limited restoration action is likely required to secure these populations.

- *Enhance stronghold* is assigned to resilient patches with lower habitat integrity (2.7% of existing EBT populations). These patches meet our criteria as strongholds, but have single significant or multiple smaller stressors present – restoration focused on addressing existing stressors within these patches can enhance the strongholds.

- *Secure and restore persistent population* strategy is assigned to redundant patches with high habitat integrity scores (11.5% of existing EBT populations). These patches meet our criteria as persistent and have relatively few stressors present – restoration of populations through non-native trout eradication or connectivity enhancements to provide more available habitat for allopatric populations, combined with limited habitat restoration effort could shift these populations to the resilient, stronghold category.

- *Restore persistent populations and habitats* strategy is assigned to redundant patches with low habitat integrity scores (19.2% of existing EBT populations). These patches meet our criteria as persistent but have single significant or multiple smaller stressors present – restoration of populations through non-native trout eradication or connectivity enhancements could shift these populations to the resilient, stronghold category, but may require concurrent habitat restoration work.

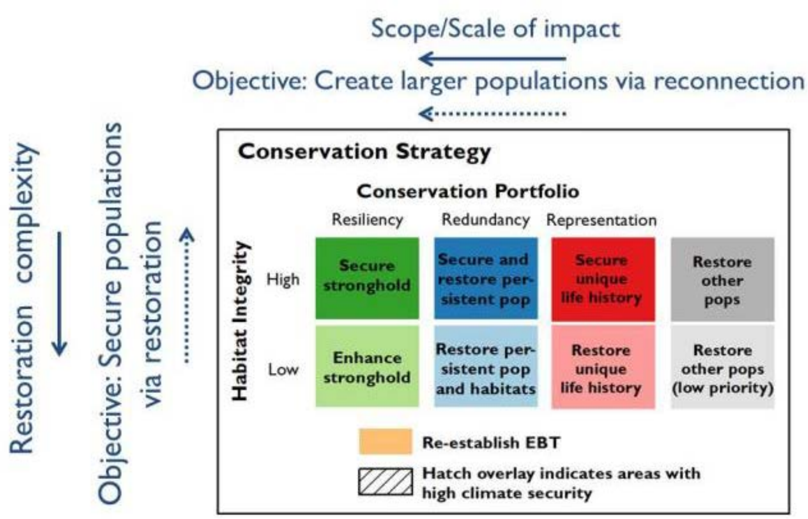

Figure 8: Conservation strategies

- *Secure unique life history* strategy is assigned to patches which do not meet portfolio redundancy and resiliency criteria, but which may contain unique life histories (all life histories except resident less productive are considered unique) and have high composite habitat condition scores (2.4% of existing EBT populations). Multiple conservation strategies may be necessary within these patches depending on EBT population status or habitat disturbance. River and lake migratory populations offer the best opportunity to shift populations into the redundant category due to their large size and productivity. Anadromous, resident lake/pond, and resident more productive populations may be small, but represent rare and unique life histories.

- *Restore unique life history* strategy is assigned to patches not meeting resiliency or redundancy criteria in the portfolio analysis, but with low habitat integrity scores (3.8% of existing EBT populations). These patches may provide some opportunity for population and habitat restoration work to shift to the redundant category.

- *Restore other populations* strategy is assigned to populations that do not meet the resiliency, redundancy, or representation criteria (57.8% of existing EBT populations). These populations are largely small allopatric or small to moderately sized sympatric resident EBT populations. Adjacent populations may provide some opportunity for reconnection activities to create additional redundant patches. As new information regarding EBT genetic status or other population attributes, such as population densities, conservation opportunities and needs for these populations may be revealed to be higher priority.

- *Re-establish EBT* is assigned to surrounding or adjacent subwatersheds – those habitats currently unoccupied by EBT – with average composite habitat integrity scores greater than 0.7 and subwatershed-average maximum 30-day average stream temperatures less than 17°C. These subwatersheds may provide an opportunity for reintroducing EBT in locations with minimal habitat restoration need and with lasting value in the face of climate change.

- Patches and surrounding subwatersheds with average stream temperatures less than 17°C are identified as locations with high climate security. All other patches may require threat abatement or mitigation efforts.

- Secondary habitat integrity and future security factors may provide additional context regarding restoration or mitigation need.

Figures 9-11 map these categories to EBT patches for the three assessment regions.

These conservation strategy categories can be useful for providing context for comparing conservation need or value across geographic areas or for characterizing EBT conservation need locally relative to other aquatic resources. For example, the categories can be equally useful for describing EBT conservation status for processes like US Forest Service Forest Plans, or for evaluating the potential benefits to EBT of individual projects. The approach also provides a loose structure for developing goals and objectives to help guide overall investment or action within and across regions. Objectives based on general conservation strategies include:

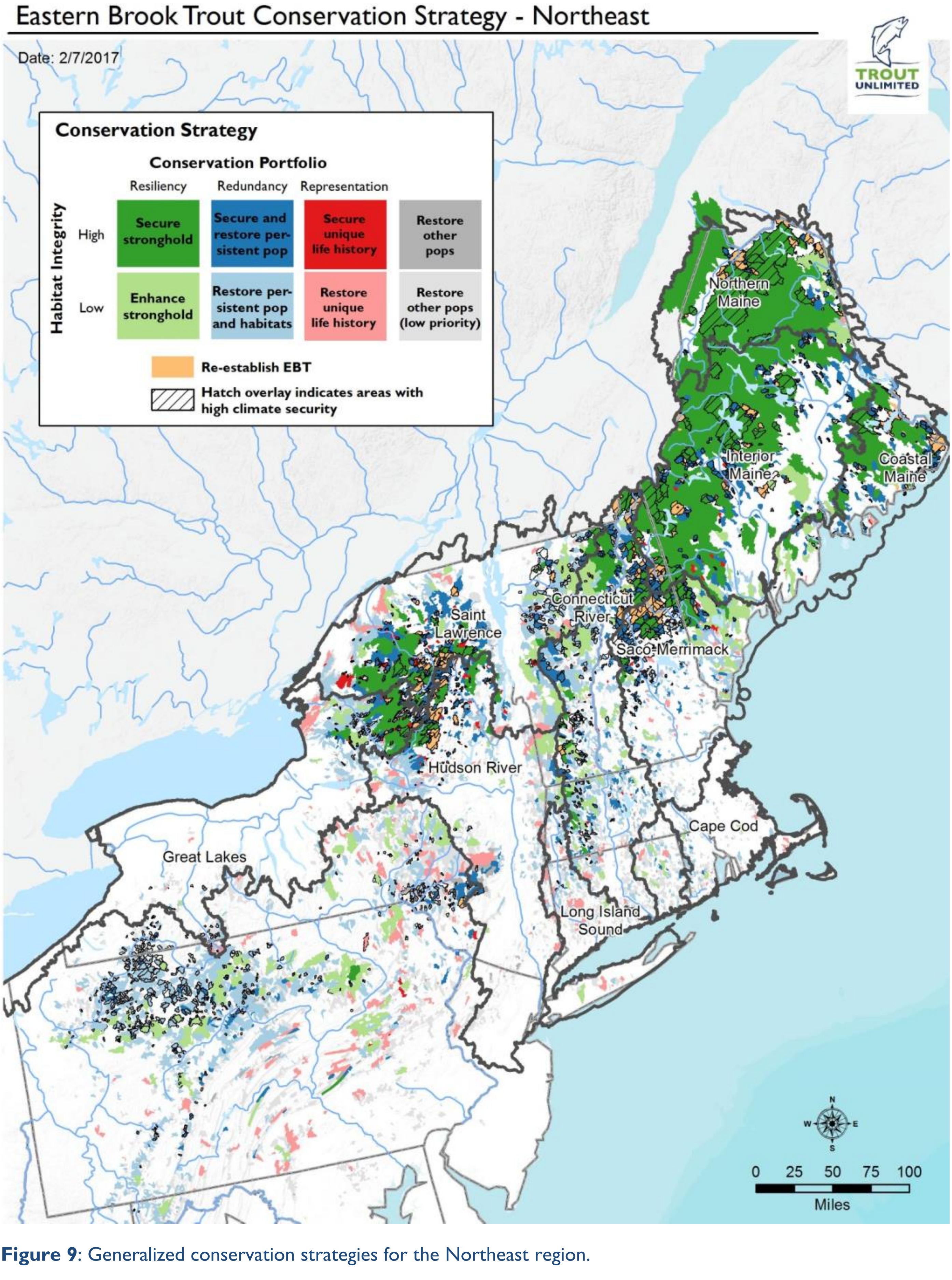

Figure 9: Generalized conservation strategies for the Northeast region.

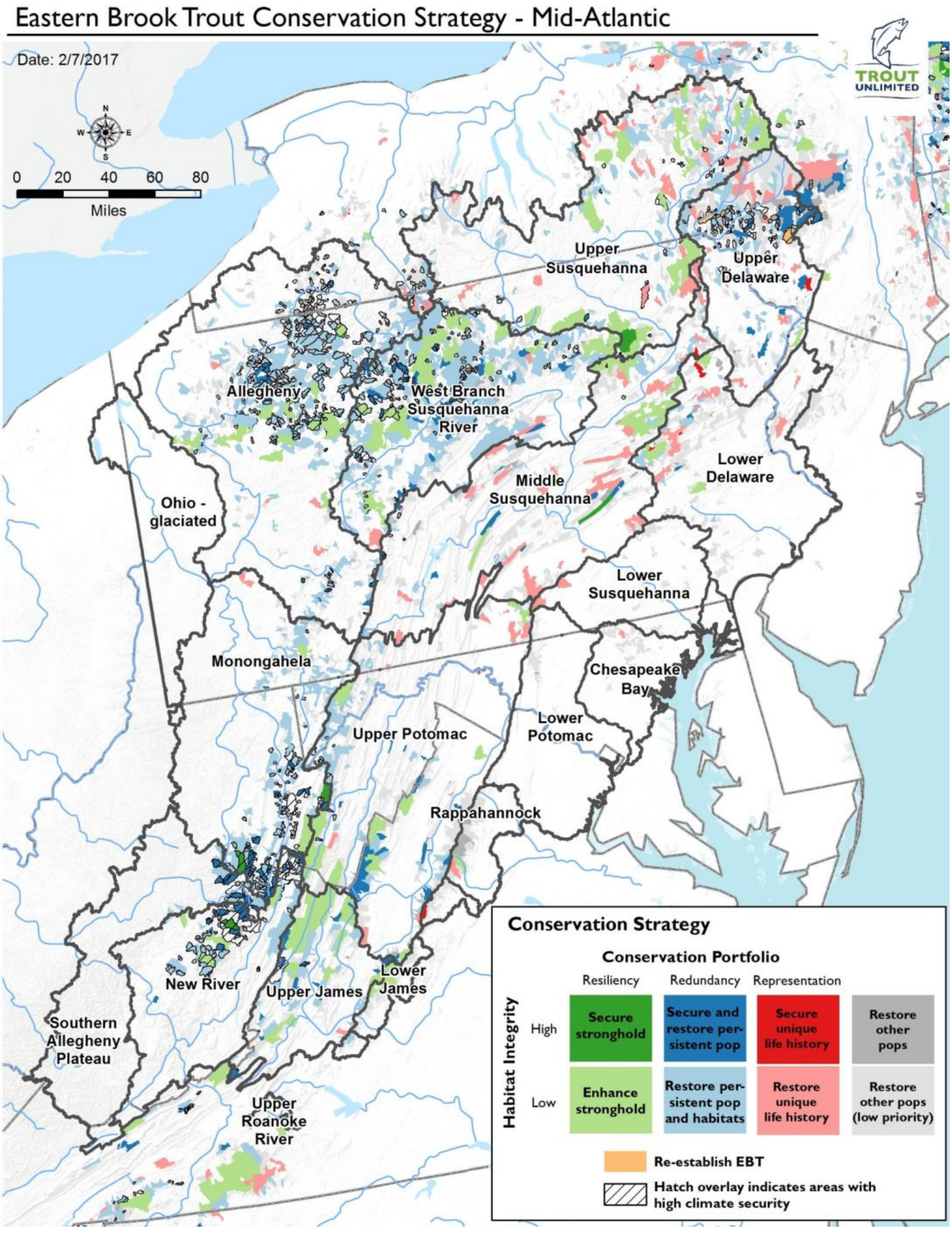

Figure 10: Generalized conservation strategies for the Mid-Atlantic region.

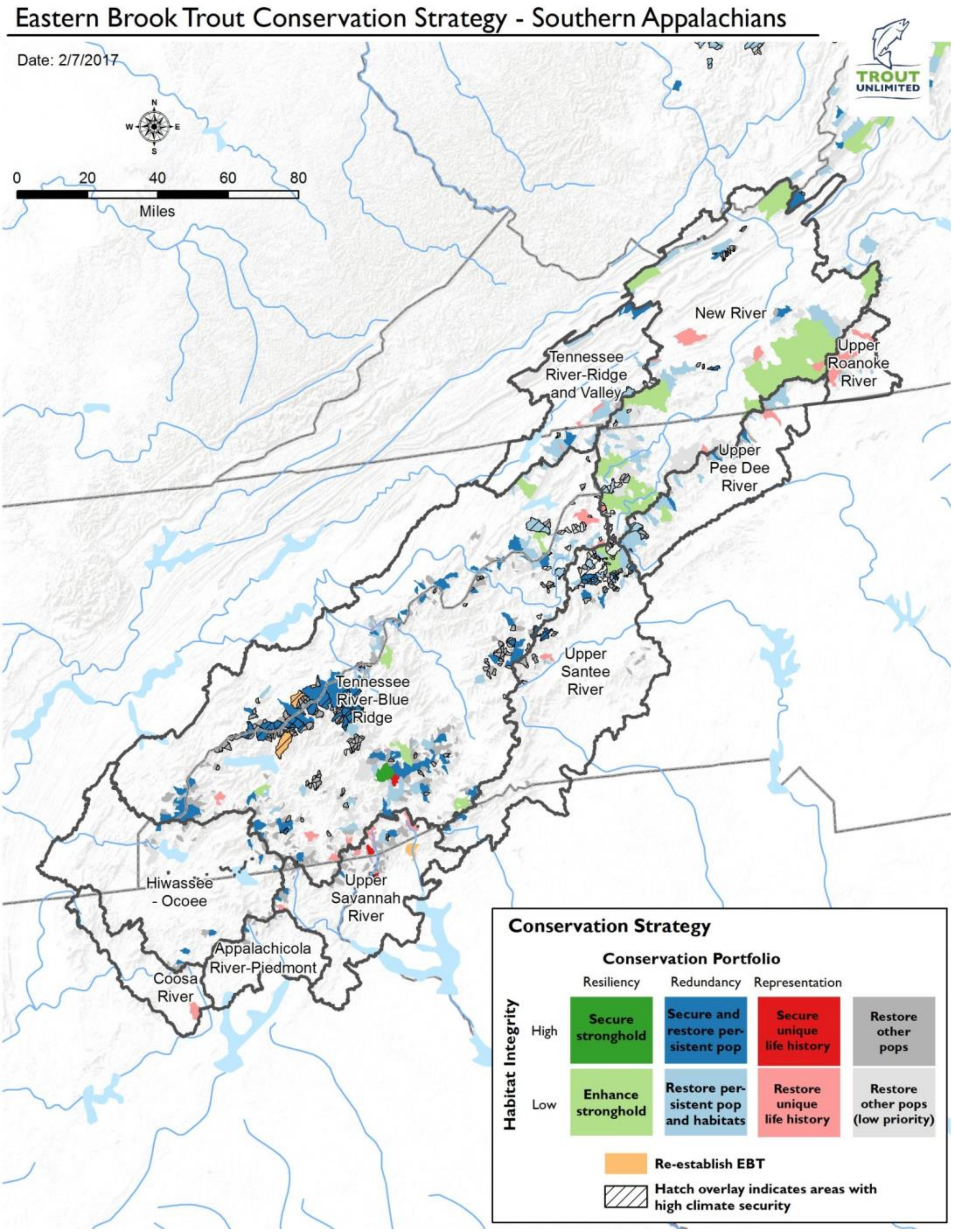

Figure 11: Generalized conservation strategies for the Southern Appalachian region.

- Secure and protect the highest value EBT populations. "Value" may be determined by portfolio results, in which resilient, stronghold populations have the greatest value, or from range-wide habitat condition and future security results, in which populations with the least amount of disturbance or vulnerability have the highest value. Securing these populations may require restoration to address sources of impairment, protection actions to prevent new stressors from occurring, and mitigation of future threats. Focusing restoration effort in those rarest, high value areas is consistent with recent evidence in support of concentrating effort in limited areas, rather than distributing effort across many areas, in order to produce measurable changes in aquatic species abundance (Roni et al. 2010).
- Restore impaired or vulnerable EBT habitats to create new high value populations. This objective involves addressing existing stressors and restoring a population into a higher category. For populations, this means removing fish passage barriers to connect larger blocks of habitat, allowing populations to move to higher 3-R categories (i.e., a redundant population meets resilient criteria following restoration). For habitats, this means addressing acute sources of impairment, such that the overall condition of habitats is markedly improved (i.e., habitat condition score increased) and patch population sizes are increased.
- Reintroduce EBT to high value, unoccupied habitats. This objective involves identifying unoccupied coldwater habitats with high habitat condition. These habitats may have historically supported EBT, but no longer do due to a local extirpation. Reintroduction may involve reconnecting small, unoccupied habitats to downstream populations via barrier removal, or translocation into previously degraded habitats which have recovered.

The conservation opportunities and strategies we identify are consistent with the key conservation actions and objectives outlined by the EBTJV in 2011. The general themes of EBTJV action strategies include starting with "protecting the 'best of the best'" – those healthiest wild EBT populations, then restoring those habitats with the greatest "likelihood of supporting stable wild brook trout populations" and "conserving unique wild EBT life history strategies" (EBTJV 2011). These strategies and objectives can be scaled according to a particular geographic scope of interest – conservation value can be defined differently at the scale of a single basin vs. within a region or at the full eastern EBT distribution.

Results and Discussion: Focal Area Assessments

While the portfolio and range-wide assessment results are interpreted to identify general conservation strategies, objectives, and priorities for each EBT population patch at the broad extent of the eastern US, the focal area analysis approaches the question of how to identify priority areas for conservation from the perspective of specific restoration actions. For each focal area, we identify a set of conservation actions commonly used to secure and restore EBT populations and habitats. These actions include restoring riparian zones, addressing sediment and nutrient runoff, monitoring EBT populations and habitat attributes such as water quality, evaluating fish passage, remediating abandoned mine lands, incorporating ecosystem services benefits to EBT conservation and mitigating climate change impacts. We link relevant data summaries for patches to each action within a Tableau data visualization tool. The tool allows users to apply criteria to filter patches based on their attributes to identify priority locations for a particular action. For example, we present information related to riparian vegetation condition, stream temperature forecasts, and modeled EBT occurrence under climate change scenarios for each patch to identify priority locations for riparian restoration. Once priority patches are identified, patch attributes can be further evaluated in a tabular format or with other map or decision support tools, including the companion ArcGIS Online webmapping application we have produced, the Ecosheds Interactive Catchment Explorer, the Riparian Restoration Decision Support Tool, or the Fish Habitat Decision Support Tool available for Chesapeake Bay tributaries.

The focal area tools for the Connecticut, Delaware, Susquehanna, and Upper Chesapeake basins are available online. A full list of datasets summarized by EBT population patch corresponding restoration activities presented in the focal areas tools is provided in Appendix 2. A user's guide for the focal area tools is presented in Appendix 3. A general framework for using the tools in conjunction with the portfolio, range-wide assessment results, and other tools is described in the next section. Appendix 4 provides example applications of the focal area tools.

Discussion: Using the Assessment Products

The assessment products described here provide a consistent and transparent structure for assembling diverse data and interpreting those data to describe broad patterns of EBT populations, the condition of their habitats, and threats those populations and habitats are likely to face in the future. The results outlined in this document (e.g., conservation strategies), are just one interpretation of the original data based on the structure of our analysis and available spatial data. The primary utility of this effort – as with many conservation planning tools – is to provide a single product for evaluating a large set of disparate but important data related to *user-defined questions about landscape scale patterns* (see Game et al. 2013). Our population patch-based summaries act as a coarse filter for identifying priorities, needs, and opportunities at spatial scales ranging from regions, states, watersheds, or individual land management agencies.

An equally useful approach is to *start instead with specific populations and pose questions about their status and condition to place them within a landscape context*. This approach is especially useful for comparing or evaluating projects and can be used as one criterion in the process of evaluating projects. Whether starting at the landscape scale to identify priority populations or with a pre-determined population of interest, the next step in evaluating project opportunities should take advantage of existing decision support tools and local information to determine the need and fit of a project. Figure 12 provides a conceptual model of this project evaluation process, in which different tools are used to identify priorities. Appendix 4 provides several example applications of the assessment tools.

Discussion: Caveats and Limitations

When evaluating the tools and products presented here, there are two important considerations related to the input data – data quality and missing data.

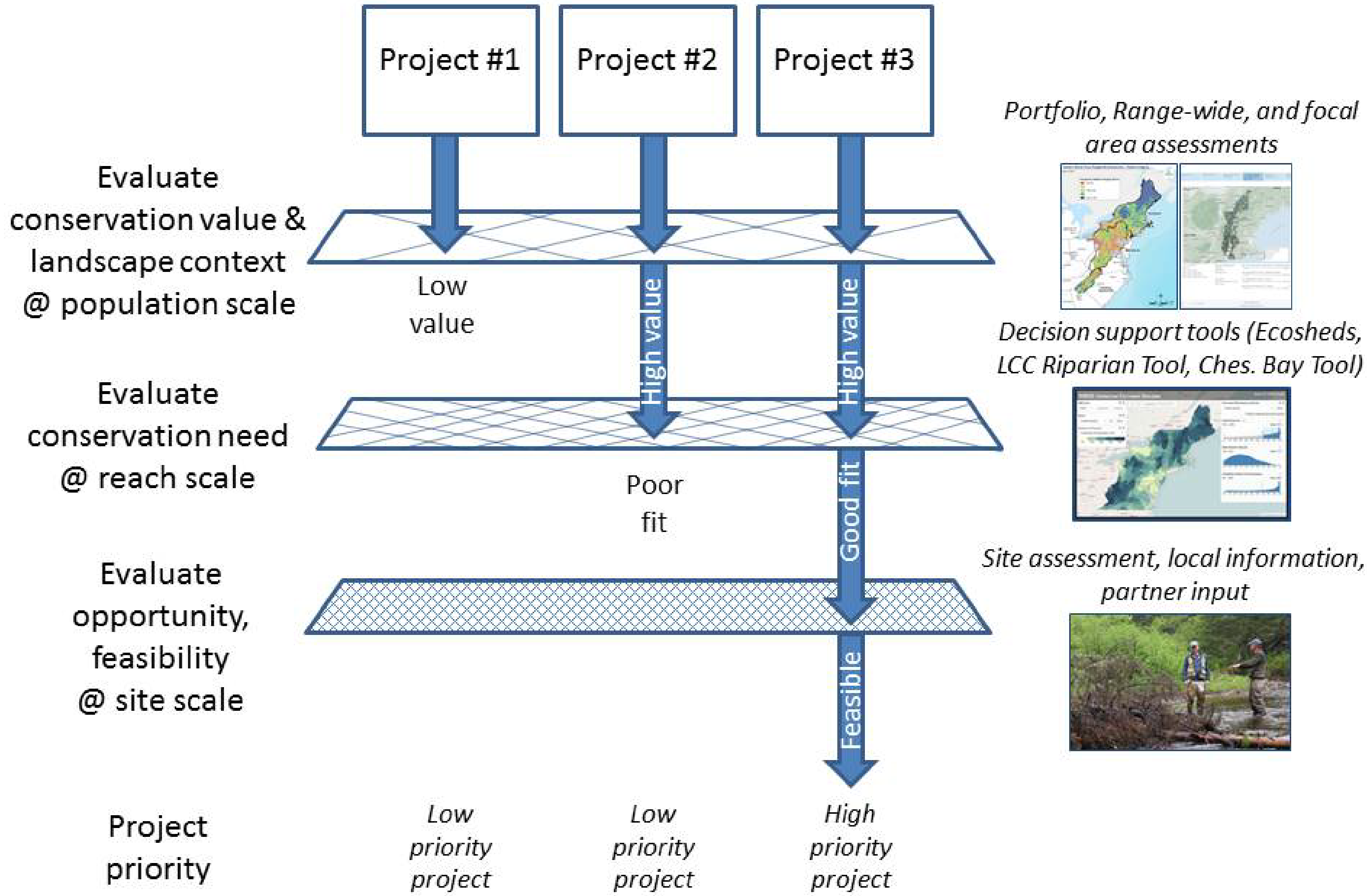

Figure 12: Conceptual model of how information from the portfoilio, range-wide assessment, and focal area tools can be used with other tools and local knowledge to help screen and prioritize conservation actions. Adapted from Dauwalter et al. 2014.

The data we use include the best available datasets for representing a particular feature. Nonetheless, data quality considerations include available information, temporal resolution, and spatial variability. Perhaps the most important consideration pertains to the base unit of our analysis, the EBTJV population patches. Patches are delineated based on available sampling information and known barriers. As new survey and passage assessment data become available, the size of existing patches may shrink or increase. These changes may fundamentally alter the interpretations within the portfolio analysis given their reliance on patch size and habitat availability as key criteria. Most habitat integrity and future security data are from the period from 2010-2015, and may not be the most up to date: the results provide a snapshot – not trend – for features and conditions for that period. Additionally, there may be variability within a particular factor not captured by the broad spatial data. For example, we use road densities to approximate sedimentation effects from road networks, but roads will vary greatly in their delivery of sediment to streams based on their surface type, quality of construction, position in the watershed, and bedrock geology (Al-Chokhachy et al. 2010). Finally, there may be local spatial datasets overlooked during the data gathering of broader, more general datasets that may provide additional resolution for considering conditions or resources on the ground – some, but not all of these datasets were gathered for the focal area analysis.

The data considered in this analysis are not intended to comprise a comprehensive list of factors affecting EBT populations, habitat, and vulnerability. Rather, they include factors that exist as broadly available, mapped data across the full range of brook trout in the eastern US and represent the most common threats affecting EBT or serve as surrogates for factors that drive EBT population dynamics. Accordingly, it is critical to consider what important factors are missing from the analysis. For the portfolio analysis, estimates of population size, observed life history, and characterization of the genetic diversity of EBT (including patterns of stocking and unique genetic lineages, such as potentially distinct Southern Appalachian brook trout (Hayes et al. 1996, Habera and Moore 2011)) would allow us to be more empirical and less predictive regarding where key elements of EBT diversity occur. As is, our results likely represent a best case scenario of existing 3-R elements. For habitat integrity results, several key factors are largely missing from the range-wide and focal area assessment results. These include non-native species (e.g., smallmouth bass *Micropterus dolomieu*), observational data related to habitat condition, or the consideration of environmental factors (e.g., soils as in Kanno et al. 2015) that may depress or amplify the impact of watershed-level land use on instream habitats. As an example of how this information could be used, stream-reach scale information regarding bank stability, channel alteration, and other fine scale factors would help characterize conditions within otherwise identical catchments based on land use factors. For future threats, broad scale models mapping vulnerability associated with increasing floods, drought, and changes in seasonality of stream flow (Melillo et al. 2014), or the lack of groundwater influence (Snyder et al. 2015) at the range-wide distribution of EBT would help elucidate where action will be required to mitigate threats.

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References

Al-Chokhachy, R., Black, T.A., Thomas, C., Luce, C.H., Rieman, B., Cissel, R., Carlson, A., Hendrickson, S., Archer, E.K. and Kershner, J.L., 2016. Linkages between unpaved forest roads and streambed sediment: why context matters in directing road restoration. *Restoration Ecology*, *24*(5), pp.589-598.

Anderson, M.G. M. Clark, C.E. Ferree, A. Jospe, A. Olivero Sheldon and K.J. Weaver. 2013. Northeast Habitat Guides: A companion to the terrestrial and aquatic habitat maps. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA. http://nature.ly/HabitatGuide.

Benke, A. C. 1990. A perspective on America's vanishing streams. Journal of the North American Benthological Society 9(1): 77-88.

Carroll, C., M.K. Phillips, C.A. Lopez-Gonzalez, and N.H. Schumaker. 2006. Defining recovery goals and strategies for endangered species: the wolf as a case study. BioScience 56(1):25-37.

Clingerman, J., T. Petty, and F. Boettner. 2015. Chesapeake Bay Watershed Brook Trout Habitat and Climate Change Vulnerability Assessment. Final report to North Atlantic Landscape Conservation Cooperative Assessment Project. Downstream Strategies. Morgantown, WV.

Coombs, J.A. and K.H. Nislow. 2014. Riparian Prioritization and Status Assessment for Climate Change Resilience of Coldwater Stream Habitats within the Appalachian and Northeastern Regions. University of Massachusetts Department of Environmental Conservation and US Forest Service Northern Research Station. Amherst, MA.

Dauwalter, D.C., J. McGurrin, M. Gallagher, and S. Hurley. 2014. Status assessment of coastal and anadromous brook trout in the United States. Wild Trout Symposium XI:192-199.

DeWeber, J.T. and Wagner, T. 2014. A regional neural network ensemble for predicting mean daily river water temperature. *Journal of Hydrology*, *517*, pp.187-200.

DeWeber, J.T. and Wagner, T. 2015. Predicting Brook Trout occurrence in stream reaches throughout their native range in the eastern United States. *Transactions of the American Fisheries Society*, *144*(1), pp.11-24.

Dunscomb, J.K., J.S. Evans, J.M. Strager, M.P. Strager, and J.M. Kiesecker. 2014. Assessing Future Energy Development across the Appalachian Landscape Conservation Cooperative. The Nature Conservancy. Charlottesville, VA.

Ecosheds. 2016. Northeast Brook Trout Occupancy Model. Available from http://conte-ecology.github.io/Northeast_Bkt_Occupancy/. Accessed September 1, 2016.

Entrekin, S. M. Evans-White, B. Johnson, and E. Hagenbuch. 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and Evolution 9: 503-511.

(EPA and USGS) US Environmental Protection Agency and US Geological Survey. 2005. National Hydrography Dataset Plus – NHDPlus. Available from http://www.horizon-systems.com/NHDPlus/NHDPlusV1_home.php. Accessed February 1, 2016.

Game, E.T., Kareiva, P. and Possingham, H.P., 2013. Six common mistakes in conservation priority setting. *Conservation Biology*, *27*(3), pp.480-485.

Haak, A.L. and Williams, J.E., 2012. Spreading the risk: native trout management in a warmer and less-certain future. *North American Journal of Fisheries Management*, *32*(2), pp.387-401.

Haak, A.L., J.E. Williams, H.M. Neville, D.C. Dauwalter, and W.T. Colyer. 2010. Conserving peripheral trout populations: the values and risks of life on the edge. Fisheries 11:530-549.

Habera, J. and Moore, S., 2005. Managing southern Appalachian brook trout: a position statement. *Fisheries*, *30*(7), pp.10-20.

Hayes, J.P., Guffey, S.Z., Kriegler, F.J., McCracken, G.F. and Parker, C.R., 1996. The genetic diversity of native, stocked, and hybrid populations of brook trout in the southern Appalachians. *Conservation Biology*, *10*(5), pp.1403-1412

Hilderbrand, R.H. and J.L. Kershner. 2000. Conserving inland cutthroat trout in small streams: how much stream is enough? North American Journal of Fisheries Management 20:513-520.

Hill, R.A., Weber, M.H., Leibowitz, S.G., Olsen, A.R. and Thornbrugh, D.J., 2016. The Stream-Catchment (StreamCat) Dataset: A Database of Watershed Metrics for the Conterminous United States. *JAWRA Journal of the American Water Resources Association*, *52*(1), pp.120-128.

Hitt, N.P., Snook, E.L. and Massie, D.L., 2016. Brook trout use of thermal refugia and foraging habitat influenced by brown trout. *Canadian Journal of Fisheries and Aquatic Sciences*, (999), pp.1-13.

Hudy, M., T.M. Thieling, N. Gillespie, and E.P. Smith. 2008. Distribution, status, and land use characteristics of subwatersheds within the native range of brook trout in the eastern United States. North American Journal of Fisheries Management 28: 1069-1085.

Kanno, Y., Letcher, B.H., Rosner, A.L., O'Neil, K.P. and Nislow, K.H., 2015. Environmental factors affecting brook trout occurrence in headwater stream segments. *Transactions of the American Fisheries Society*, *144*(2), pp.373-382.

MacAvoy, S.E. and Bulger, A.J., 1995. Survival of brook trout (Salvelinus fontinalis) embryos and fry in streams of different acid sensitivity in Shenandoah National Park, USA. *Water, Air, and Soil Pollution*, *85*(2), pp.445-450.

Melillo, J.M., Richmond, T.T. and Yohe, G., 2014. Climate change impacts in the United States. *Third National Climate Assessment*.

Moore, J.W., Yeakel, J.D., Peard, D., Lough, J. and Beere, M., 2014. Life-history diversity and its importance to population stability and persistence of a migratory fish: steelhead in two large North American watersheds. *Journal of Animal Ecology*, *83*(5), pp.1035-1046.

North Atlantic Landscape Conservation Cooperative. 2016. Connect the Connecticut. Available from

(NRCS) U.S. Department of Agriculture Natural Resource Conservation Science. 2014. Watershed boundary dataset. Available from http://datagateway.nrcs.usda.gov. Accessed November 5, 2015

Olivero Sheldon, A., Barnett, A. and Anderson, M.G. 2015. A Stream Classification for the Appalachian Region. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. BioScience 47(11): 769-784.

Rieman, B.E. and Dunham, J.B., 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. *Ecology of Freshwater Fish*, *9*(1-2), pp.51-64.

Roni, P., Pess, G., Beechie, T. and Morley, S., 2010. Estimating changes in coho salmon and steelhead abundance from watershed restoration: how much restoration is needed to measurably increase smolt production?. *North American Journal of Fisheries Management*, *30*(6), pp.1469-1484.

Shafer, M.L., and B.A. Stein. 2000. Safeguarding our precious heritage. Pages 301-321 in, B.A. Stein et al., editors. Precious heritage: the status of biodiversity in the United States. Oxford University Press.

Sharpe, W. E., Leibfried, V. G., Kimmel, W. G. and DeWalle, D. R. (1987), The Relationship Of Water Quality And Fish Occurrence To Soils And Geology In An Area Of High Hydrogen And Sulfate Ion Deposition. JAWRA Journal of the American Water Resources Association, 23: 37–46. doi:10.1111/j.1752-1688.1987.tb00782.x

Snyder, C.D., Hitt, N.P. and Young, J.A., 2015. Accounting for groundwater in stream fish thermal habitat responses to climate change. *Ecological Applications*, *25*(5), pp.1397-1419.

Stranko, S.A., R.H. Hilderbrand, R.P. Morgan II, M.W. Staley, A.J. Becker, A. Roseberry-Lincoln. 2008. Brook trout declines with land cover and temperature changes in Maryland. North American Journal of Fisheries Management 28:1223-1232

The Nature Conservancy, Partnership for the Delaware Estuary, and Natural Lands Trust. 2011. Delaware River Basin Priority Conservation Areas and Recommended Conservation Strategies. Final Report To National Fish and Wildlife Foundation.

Theobald, D.M., 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecol Soc. 10(1), article 32 (online). Retrieved on March 25, 2008 from http://www.ecologyandsociety.org/vol10/iss1/art32/ES-2005-1390.pdf.

Weidner, E. and A.Todd. 2009. From the Forest to the Faucet – Drinking Water and Forests in the US. USDA Forest Service, Washington D.C.

Wagner, T., J. T. Deweber, J. Detar, and J. A. Sweka. 2013. Landscape-scale evaluation of asymmetric interactions between brown trout and brook trout using two-species occupancy models. Transactions of the American Fisheries Society 142: 353-361.

Wagner, T. and Midway, S.R., 2014. Modeling spatially varying landscape change points in species occurrence thresholds. *Ecosphere*, *5*(11), pp.1-16.

Waters, T. F. 1983. Replacement of brook trout by brown trout over 15 years in a Minnesota stream: Production and abundance. Transactions of the American Fisheries Society 112: 137-146.

Wehrly, K.E., L. Wang, and M. Mitro. 2007. Field-based estimates of thermal tolerance limits for trout: Incorporating exposure time and temperature fluctuation. Transactions of the American Fisheries Society 136: 365-374.

Weltman-Fahs, M. and Taylor, J.M., 2013. Hydraulic fracturing and brook trout habitat in the Marcellus Shale region: potential impacts and research needs. *Fisheries*, *38*(1), pp.4-15.

Williams, J.E., Haak, A.L., Gillespie, N.G. and Colyer, W.T., 2007. The Conservation Success Index: synthesizing and communicating salmonid condition and management needs. *Fisheries*, *32*(10), pp.477-493.

Whiteley, A.R., Coombs, J.A., Hudy, M., Robinson, Z., Colton, A.R., Nislow, K.H. and Letcher, B.H., 2013. Fragmentation and patch size shape genetic structure of brook trout populations. *Canadian Journal of Fisheries and Aquatic Sciences*, *70*(5), pp.678-688.