DATABASE DEVELOPMENT AND SPATIAL ANALYSES IN SUPPORT OF TENNESSEE'S STATE WILDLIFE ACTION PLAN

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Database development and spatial analyses in support of Tennessee's State Wildlife Action Plan

Contents

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INTRODUCTION

The Nature Conservancy (TNC) worked with the Tennessee Wildlife Resources Agency on the development of the Tennessee State Wildlife Action Plan (TN-SWAP), which was adopted in 2005. To support this planning effort, a GIS and relational database management system (RDBMS) were developed to manage the large amounts of data on species of Greatest Conservation Need (GCN), their habitats, and problems affecting these species and habitats. Terrestrial, aquatic, and subterranean habitats were classified and mapped, and habitat preferences for over six hundred faunal species were assigned by taxonomic experts involved in the planning effort. The database calculated and synthesized scoring indexes of species rarity, occurrence viability, habitat preference, and spatial proximity to a habitat type. This analysis allowed the spatially explicit identification and prioritization of habitats critical for the conservation of SGCN fauna across Tennessee.

The architecture of the SWAP database was designed to facilitate the incorporation of new and revised data over time. Since its initial development, various components of the database have been updated, revised, and expanded to support new functionality. In many cases, the needs of subsequent planning projects were the impetus for these revisions, but whenever possible, they have been done for the entire state of Tennessee, not just the specific project area. This report provides an overview of the new datasets and analyses utilized by the 2015 TN-SWAP planning team to identify statewide habitat priorities and address major problems affecting GCN species.

MAPPING PRIORITIES FOR CONSERVATION ACTION

Overview

The basic approach for identifying priority areas statewide is to identify the target GCN species, and then weight those species by their relative imperilment and need for conservation investment. Next, species occurrence datasets are compiled to assemble the best available information documenting where and when those species have been observed. Information associated with the data records are used to assess the likelihood that that species still persists currently at that location, and when possible, how healthy the population evidenced by the occurrence appears to be according to field observations.

For terrestrial and aquatic species, individual occurrence observations are used to develop a potential spatial footprint of a population in the vicinity of the observation. This population footprint is derived and mapped according to the estimated mobility of the species in question, as determined by taxonomic experts and maintained by NatureServe. The base mapping units for terrestrial and subterranean species footprints are standardized 100-acre hexagons, aggregated to 700-acre rosettes. For aquatic species, the National Hydrography Dataset Plus Version 2 (NHDPlusV2) catchments and stream segments are used. Terrestrial species footprints extend outward in all directions around the occurrence observation; for aquatic species, the footprint extends upstream and downstream of the occurrence. For terrestrial species, taxonomic experts assessed the suitability of ecological systems defined by NatureServe as potential habitat for each species. A statewide map coverage of the ecological systems compiled by Southeast GAP is then used to match locations of habitats on the landscape to species within their potential population footprints.

Updates to the Species Occurrence Datasets

At the time of initial development in 2005, the TN-SWAP database included approximately 25,000 element occurrence records of 664 species identified as species of greatest conservation need (GCN) by the TN-Natural Heritage (TN-DNH) database, as well as a number of other governmental and academic datasets (TWRA 2005). During the last decade, the original occurrence database has undergone a number of revisions and expansions, as new records were collected and new datasets became available.

The GCN species list itself has also undergone significant revision and expansion. New field survey work, particularly in subterranean environments, has added numerous species either potentially new to science, or not previously known to occur in Tennessee. Additionally, the taxonomy of a number of subterranean species has been subsequently clarified. To better support planning efforts for freshwater mollusks, information on priority streams and host fish species contained in the *Plan for the Controlled Propagation, Augmentation, and Reintroduction of Freshwater Mollusks of the Cumberlandian Region* was added to the database, as was additional information on host species compiled by Virginia Tech researchers (Cumberlandian Region Mollusk Restoration Committee 2010 and Ostby 2010, pers. comm.). Over 131,000 observations of host fish species are now captured in the database.

For the 2015 TN-SWAP, the planning team selected 1,499 species as designated GCNs including the addition of 568 plant species, which were not selected as GCNs in 2005. The final set of occurrence information utilized in the 2015 plan includes over 325,000 observation records from the following primary sources: TN-DNH, TWRA's Tennessee Aquatic Database System (TADS), TWRA's aquatic and terrestrial scientific collection permits, the TWRA non-game inventory program, Tennessee Valley Authority aquatic surveys, and eBird datasets. The table below compares the number of species occurrences available in the database for use in GCN determination and habitat priority mapping during the 2005 planning compared to occurrence updates available in 2015.

GCN group	2005	2015
Aquatic	5,268	149,224
Subterranean	961	7,000
Terrestrial	19,396	160,166
Plants	Not included	9,779
TOTAL	24,664	326,169

GCN Species Prioritization Methodology

During the plan development phase for the 2005 SWAP, a conservation priority score was defined for each GCN species based on its global rarity, as defined by NatureServe G-Rank, as well as rarity rating within Tennessee (NatureServe S-Rank). Equal weightings were applied to global and state rankings in the prioritization scheme. In subsequent model development, in order to emphasize potential extinction risk, the G-Rank is scaled to a maximum of 50 points, with TN S-Rank scaled to 30 points maximum. Added together, these ranks comprise the rarity rating (R) of the species. The prioritization rating has been expanded to include both federal and Tennessee state legal listing status (each scaled to 10 points maximum) to account for other considerations such as declining population trends that may not be reflected in the original G- or S-Ranks. Federal and Tennessee listing scores are added to give the overall legal status rating (L) of the species, and the 2 scoring components are added together to give the overall conservation priority score (RL) for each species.

GCN Species Occurrence Viability Rating Methodology

The 2005 TN-SWAP developed an index of viability (V) for every species occurrence. Rather than a true population viability analysis, this viability rating was intended to capture the relative confidence that the species currently persists on the landscape at the location evidenced by the occurrence record.

The 2005 method began with combining observations of each species within 100m of each other together into occurrence groups, resulting in unique instances of a given species at a given location. "Viability" was based at a very minimum on the year of last observation (30 pts.), and where available, NatureServe EO-Rank (50 pts.), the total number of raw observations (10 pts.), and time between first and last observation (10 pts.). The score components were added together to give the final overall "viability" score. Occurrences for which the date of last observation was unknown were excluded from the prioritization analyses, resulting in the elimination of many data points. Additionally, updating the model with new observation data proved cumbersome, as new observations needed to be processed and merged with existing records to give a new set of occurrence groups before viability could be calculated.

In the current iteration of the model, occurrence viability (V) is calculated for each observation and has been simplified to include just the age of the record (i.e. year of last observation) and the NatureServe EO-Rank. Records for which the date of last observation is not known are given a nominal score of 20 points out of a maximum of 100. Observations without a NatureServe EO-Rank are assigned a score of 40 out of 100, equivalent to the score assigned to EO-Ranks of 'E' (i.e., extant). The two components are then multiplied, and the result divided by 100 to retain a 100-point scale. This approach accounts for the uncertainty associated with records with missing date information without excluding them entirely from analyses. Raw observations are then linked to the appropriate unit of analysis (rosette or stream segment), and grouped to remove duplicate instances of a given species at a given analysis unit, with the maximum viability score used in subsequent analyses.

Terrestrial Habitat Prioritization

Habitat Preference Assignments for Species

As part of the 2005 planning effort, a database of expert-defined preferences of GCN fauna for habitats occurring in the Tennessee, as defined by NatureServe's Ecological System classification, was developed and populated. Taxonomic experts gave a rating of "preferred," "suitable," "marginal," or "unsuitable" for every natural ecological system, within each different terrestrial ecoregion of the state, for every GCN species. During a separate project effort in 2009, plant biologists at TN-DNH completed similar habitat preference ratings for plant species tracked in their state system, and these preference assignments have been incorporated into the database. Details of species and habitat preference assignments are provided in Appendix D of the 2015 SWAP (Tennessee State Wildlife Action Plan Team 2015). Habitat preferences were assigned weighting values for (P) in the 2015 prioritization scheme as follows: 10 points for preferred, 5 points for suitable, and 2 points for marginal habitats.

Habitat Mapping

In the 2005 version of the SWAP model, terrestrial habitat mapping was based on the 1992 Southeast Gap Analysis Project's (SEGAP) vegetation coverage. This coverage was crosswalked to the NatureServe ecological system classification, filtered to eliminate patches of 6 or fewer pixels, converted to vector format, and overlaid with roadless blocks derived from U.S. Census Topologically Integrated Geographic Encoding and Referencing (TIGER) data. The resulting coverage of roughly 280,000 habitat patches served as the units of analysis for the terrestrial model. For occurrence groups with preference for each habitat patch, a distance score was calculated, as a percentage of the NatureServe suitable habitat separation distance (SHSD) of the species.

This resulted in a table of unique occurrence group/habitat patch combinations, with prioritization scores based on G-Rank and S-Rank ratings of imperilment (GS), occurrence group viability (V), occurrence group to habitat patch distance (D), and preference of the species for the habitat (P). Occurrences were grouped into presumed populations based on their SHSD and, for each population, the maximum GSVDP score was selected. The conservation priority of each habitat patch was calculated by summing corresponding GSVDP scores for all inside or adjacent populations. The high variability in habitat patch size meant high variability in spatial precision of the analysis, and biased scores toward large matrix habitat patches, as their large footprints meant they were more likely to contain or be close to a larger number of occurrence groups.

The 2015 SWAP terrestrial model uses the 2001 SEGAP ecological system coverage for mapping terrestrial habitats. Based on classification of circa 2001 Landsat imagery, this coverage is able to identify matrix- and large-scale habitat classes, but the 30-meter resolution of the source Landsat data makes identification of small-patch and linear habitats difficult. Despite these limitations, it is considered a major improvement over the outdated and less accurate 1992 habitat coverage used in the 2005 model.

In the 2015 model, the irregular TIGER-based roadless block units have been replaced with uniform units of analysis. Initially a GIS coverage of roughly 270,000 100-acre hexagons covering the state of Tennessee was generated for use. However, the large number of resulting hexagon/habitat/occurrence record combinations proved onerous, and the fine grain size more spatially precise than warranted by the underlying input data. The hexagons were therefore aggregated into clusters, with a single hexagon in the center surrounded by six adjacent hexagons, resulting in 700-acre rosettes, of which there are approximately 40,000 covering the state. The rosettes were then overlaid with the 2001 ecological system coverage. The resulting layer of roughly 400,000 rosette/ecological system class combinations comprises the units of analysis in the current terrestrial prioritization model.

To model potential species footprints from locations of known observations, rosettes surrounding terrestrial occurrences were assessed based the occurrence viability score (V), as well as distance to occurrence (D), as a percentage of 4 times the NatureServe suitable habitat separation distance of the species, with maximum distance/viability score combinations selected for each species/rosette pair. The result is potential species distribution footprint around known occurrence locations. The larger 4x SHSD search window of the current model results in a much larger spatial footprint of potential habitat occupancy than the original version, which used a 1x SHSD maximum. Figure 1 is an example of the map outputs of priority locations by 700 acre rosette for Pygmy Salamander conservation based on the 2015 footprint calculations.

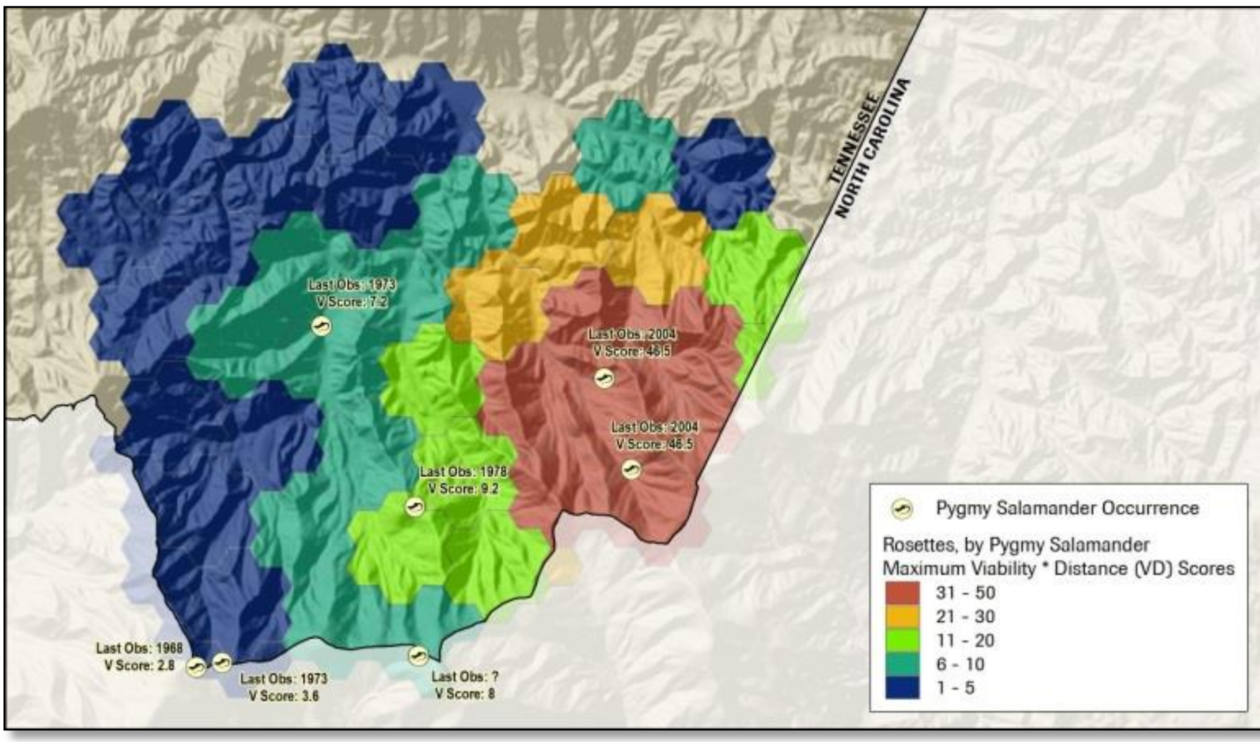

Figure 1. Prioritized locations for Pygmy Salamander conservation based on known occurrences, dates of last observations, and NatureServe suitable habitat separation distances.

In the relational database, the occurrence-based species/rosette footprint table was joined to the habitat/rosette table, and habitat/species combinations were scored based on species imperilment scores (RL), occurrence viability*distance (VD), and habitat preference (P) for all mapped ecological system units within each rosette. This table has roughly 3,000,000 records of unique species-habitat-rosette combinations. Priority scores of habitats within each rosette were then calculated by summing the corresponding RLVDP scores for all associated species:

$$\text{Terrestrial Habitat Priority} = \sum_{i=1}^{n} (\mathrm{RL}*\mathrm{V}*\mathrm{D}*\mathrm{P}]\!]_{\mathrm{i}}$$

where n is the number of species whose footprints fall within the mapped habitat. Figure 2 demonstrates how the age of occurrence records, distribution of suitable habitat, and dispersal distance capability help contribute to the overall rosette scores to better target conservation investments.

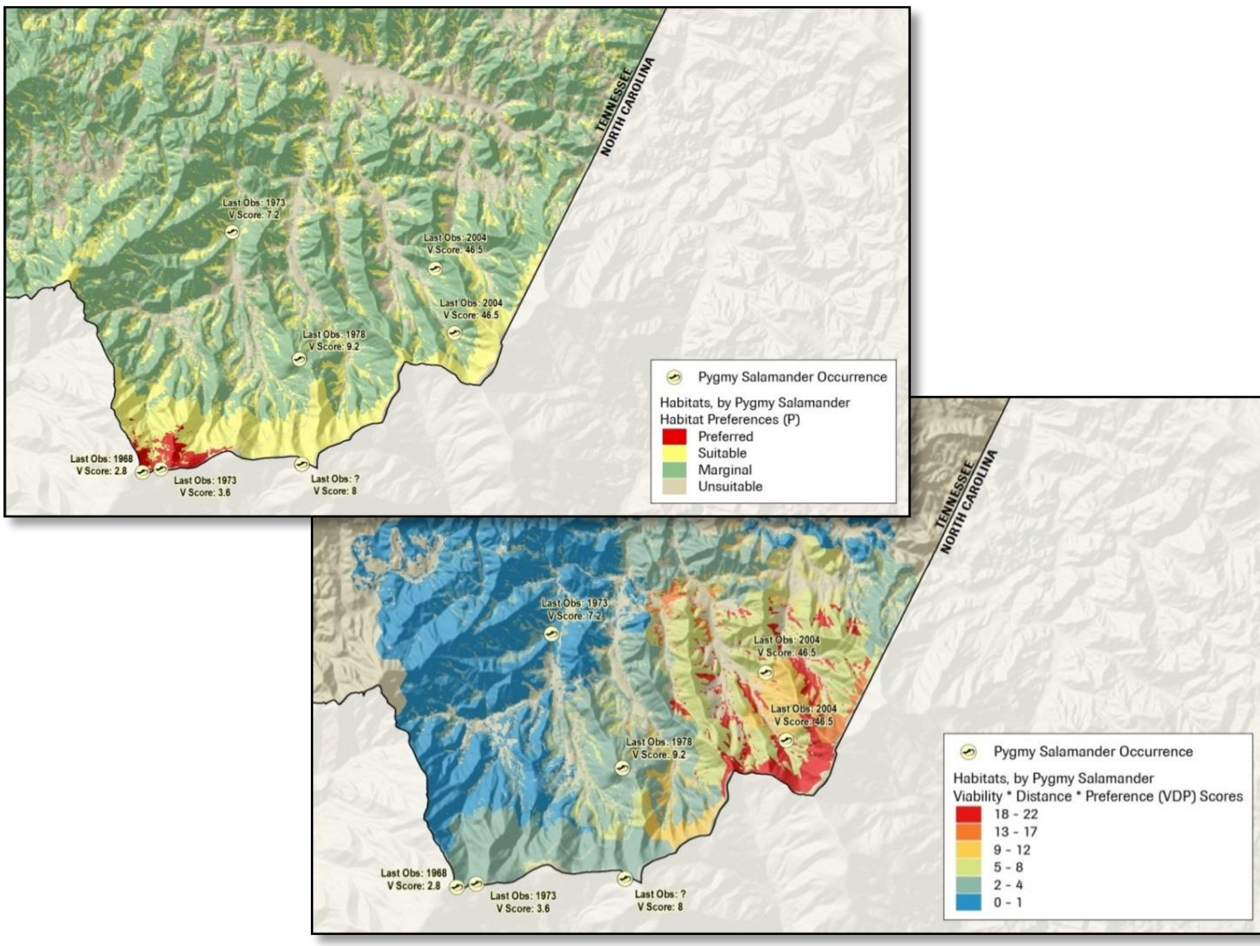

Figure 2. Illustration of how more recent observations, available suitable habitat, and known dispersal capacity of the Pygmy Salamander help identify better locations for targeting conservation activities.

Aquatic Habitat Prioritization

Habitat Mapping

Since its initial development, the aquatic component of the SWAP database has also been extensively revised and refined. The 2005 version of the SWAP aquatic model used 12-digit hydrologic units (HUC12) as the units of analysis. Aquatic occurrences were overlaid with the HUC12 coverage, and assigned to the HUC12 that they occurred within. Similar to the methods used for terrestrial species, aquatic specie occurrences were grouped into unique species/HUC12 combinations, with the maximum occurrence viability score (V) within each HUC12 used for that species. Aquatic habitat priorities were calculated for each HUC12 based on the G-Rank and S-Rank imperilment score, multiplied by V score, of all species they contained.

To serve as a foundation for the 2015 version of the aquatic TN-SWAP model, and to support evaluation of potential impacts of upstream activities and conditions to downstream aquatic fauna, an Access-based hydrologic modeling framework was developed utilizing National Hydrography Plus Version 2 (NHDPlusV2) datasets. Built upon the 1:100,000-scale National Hydrography Dataset (NHD) and 1:24,000-scale digital elevation models (DEM), NHDPlusV2 defines the watershed catchment areas draining into each individual stream segment in the hydrologic network. The dataset also defines the hydrologic upstream/downstream connections between individual stream segments, as well as providing a number of other hydrologically relevant attributes, such as mean annual flow velocities and volumes. The data were compiled for the entire Tennessee and Cumberland River basins, as well as the 8-digit hydrologic unit sub-basins of the Mississippi, Barren and Conasauga Rivers that at least partially occur in the state.

Dam locations and GIS attributions from the 2013 National Inventory of Dams (NID) dataset and the 2012 National Anthropogenic Barrier Dataset (NABD) were compiled for use in the 2015 aquatic model. Dams were linked to their corresponding NHDPlusV2 stream segments, and normal storage values from the dam data, as well as NHDPlusV2 flow volumes at the linked stream segments, were used to estimate mean annual residence time of water behind dams. This completed dataset allows the characterization and analysis of watersheds upstream of each segment in the NHDPlusV2 stream network, weighted by the mean annual flow travel time and percent flow contribution of the individual catchments within that watershed (see Figure 3).

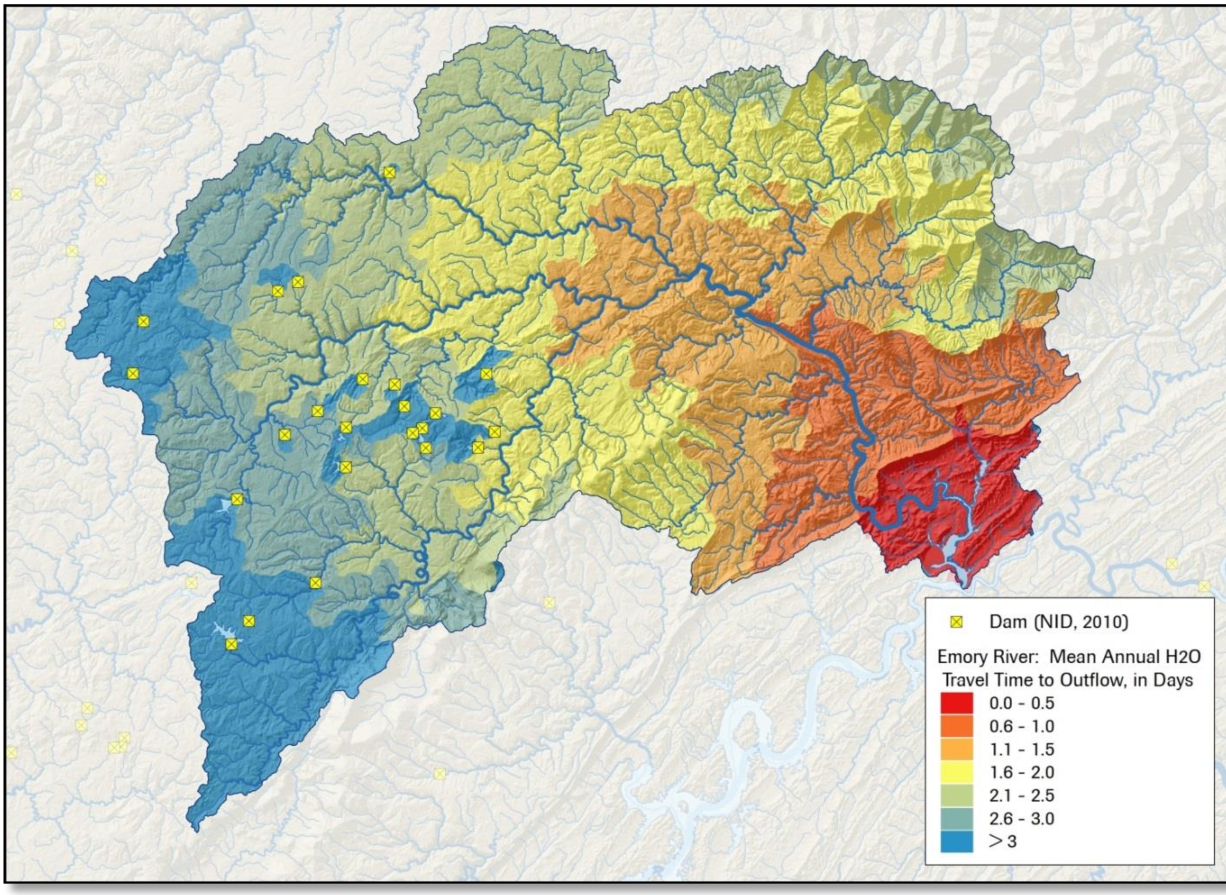

Figure 3. Example of hydrologic analysis between catchments and points downstream in the Emory River watershed. Note how the presence of small dams creates disconnects in stream flow contributions in sections of the upper watershed.

Mapping Species Distributions from Known Occurrences

To interpolate potential distribution footprints from the GCN and mollusk host fish occurrence data, occurrences were snapped to their nearest NHDPlus stream segment, and grouped to remove duplicates, with the maximum occurrence viability score (V) selected for each species/stream segment pair. Stream segments upstream and downstream of those with known species occurrences were evaluated and scored, based on species rarity/legal status score (RL); occurrence viability score (V); instream separation distance as a percentage of 2 times the NatureServe suitable habitat separation distance (D) and percent deviation of mean annual flow volume from that of the reference stream segment containing the occurrence (Q). Stream segments with Q scores less than 50, meaning that their mean annual flow volume is less than half or more than twice that of the reference stream segment, were excluded from the footprints. The component scores for the species/stream segment pairs were then multiplied together to give the overall habitat priority score for that species in that stream habitat.

$$\text{Aquatic Habitat Priority } = \sum_{i=1}^{n} (RL * V * D * Q]\!]_i$$

where n is the number of species whose footprints fall within the stream segment.

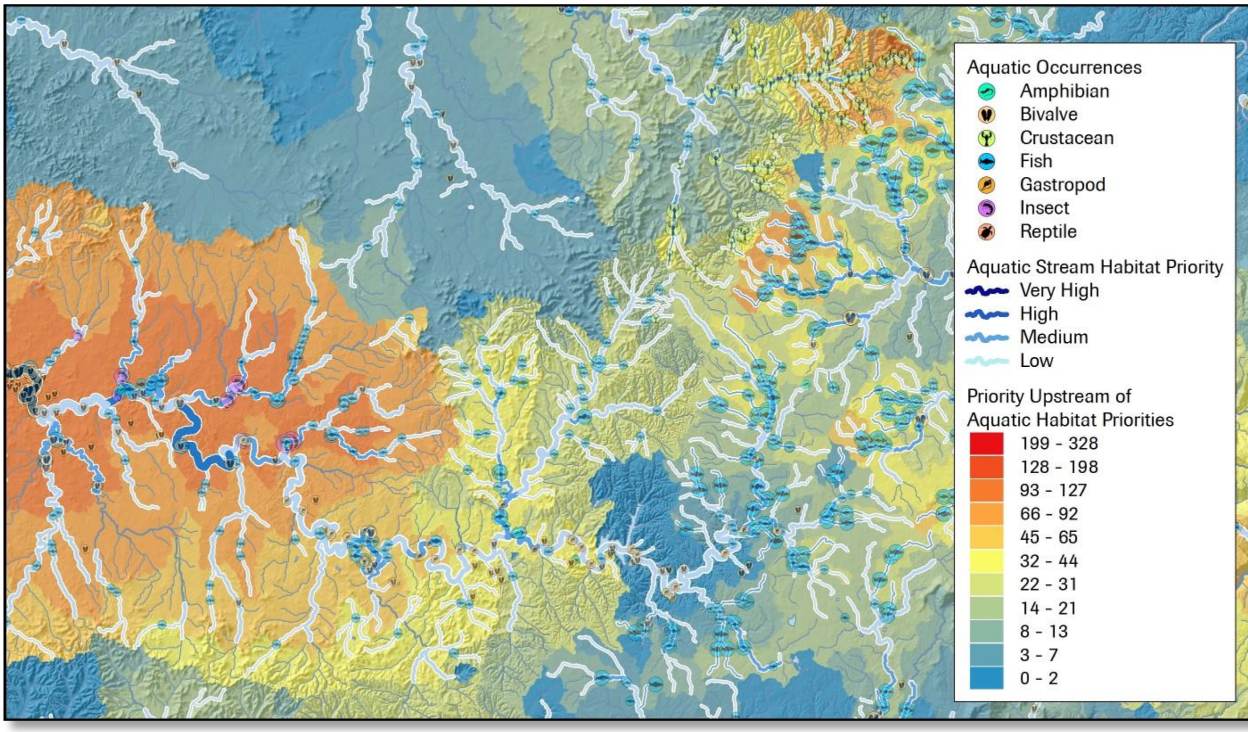

Figure 4. Example of stream segment and small watershed (catchment) area prioritization based on the aquatic habitat scoring formula.

Dams are considered barriers to faunal movement, and so were not crossed in assessing potential occurrence extent. The resulting table contains approximately 120,000 species/stream segment combinations. Similar to the terrestrial habitat analysis, the RLVDQ scores for all corresponding species records were totaled to give the overall habitat priority of each stream segment.

Because stream segment length is highly variable, he amount of habitat represented by each stream segment, as a function of segment length as a percentage of the NatureServe suitable habitat separation distance for the species, was also calculated, and used to weight the RLVDQ scores of each species-stream segment combination. Small watershed catchment areas upstream of instream habitats were prioritized based on proximity, as a function of instream water travel time, as well as relative flow contribution, to prioritized downstream habitat segments. Figure 4 demonstrates the map outputs of both stream segment formulas.

In addition to longitudinal instream flow relationships between upstream catchments and downstream habitat streams, lateral connectivity relationships between lands and streams within catchments were evaluated as well. For the Tennessee, Cumberland, Barren, and Conasauga river basin portions of the overall analysis area, an active river area (ARA) analysis and mapping had been performed by The Nature Conservancy (Smith et al. 2008). The ARA identifies a number of areas important to lateral hydrologic connectivity, process, and function, including material contribution zones, meander belts, floodplains, terraces, and riparian zones.

For the Mississippi basin, which was not covered by the ARA analysis, FEMA flood zones and buffers around NHDPlusV2 stream segments were used to approximate floodplain and material contribution zones. The ARA and flood zone-based areas were then overlaid with the NHDPlusV2 catchments, and resulting areas within catchments were assigned weights based on relative connectivity to the stream environment and potential importance to hydrologic process and function.

Combined with the upstream/downstream relationships between catchments and streams, this allowed an assessment of the potential importance and conservation value of upland, floodplain, and riparian zones to adjacent and downstream stream habitats for GCN species.

Subterranean Habitat Prioritization

The 2005 SWAP database included roughly 1,700 observations of subterranean species in 400 cave systems. With subsequent expansion to incorporate previously unavailable datasets and results of new survey efforts, the database now documents approximately 7000 observations from nearly 900 cave systems throughout Tennessee.

In the 2005 version of the SWAP subterranean model, occurrences were grouped into unique species/cave system combinations, with the maximum occurrence viability score (V) within each cave system used for that species. Subterranean habitat priorities were calculated for each cave system based on the G-Rank and S-Rank imperilment score, multiplied by V score, of all species they contained.

In the 2015 version of the model, conservation priority ratings of karst species and their occurrences are based only on NatureServe G-Ranks, when available, and on estimates of probable G-Rank designation for species not in the NatureServe database. Despite recent survey efforts, scientific understanding and documentation of karst species and their occurrences in the state remain low and highly fluid, resulting in a lag between scientific knowledge and official federal and state legal designations.

For the current model, ratings of species reliance on subterranean environments (e.g. troglobites vs troglophyles, etc.) were compiled, and converted to scores of karst affinity (KA), analogous to the habitat preference scores used for terrestrial species and associated ecological systems. Bats are the only faunal group for which viability (V) scores were calculated and used in assessing subterranean priorities, following the same methodology used for terrestrial and aquatic species.

Subterranean observation records are assigned to the cave system from which they are documented, and then grouped to remove duplicates, resulting in unique species/cave system records of occurrence. Habitat priorities are calculated for each cave system, based on totaling the global rarity (G) and karst affinity (KA) scores of associated occurrences:

$$\text{Cave System Priority} = \sum_{i=1}^{n} (G * KA)_i$$

where n is the number of known occurrences in the cave system.

Using the 100 acre hexagon units of analysis from terrestrial modeling, areas around cave system entrances were assessed based on distance to cave systems with documented biological priorities. The occurrences of karst species which occupy dry habitats within caves were assigned a maximum distance of 2.5km to approximate the extent of the organic recharge zone. For bats and species occupying wet areas and cave streams, a maximum distance of 5km was used, to reflect the higher mobility and potential hydrologic recharge zone of those species groups, respectively. For each hexagon, GKAD scores from nearby cave systems were calculated and totaled together to give the karst conservation priority of that area (see Figure 5).

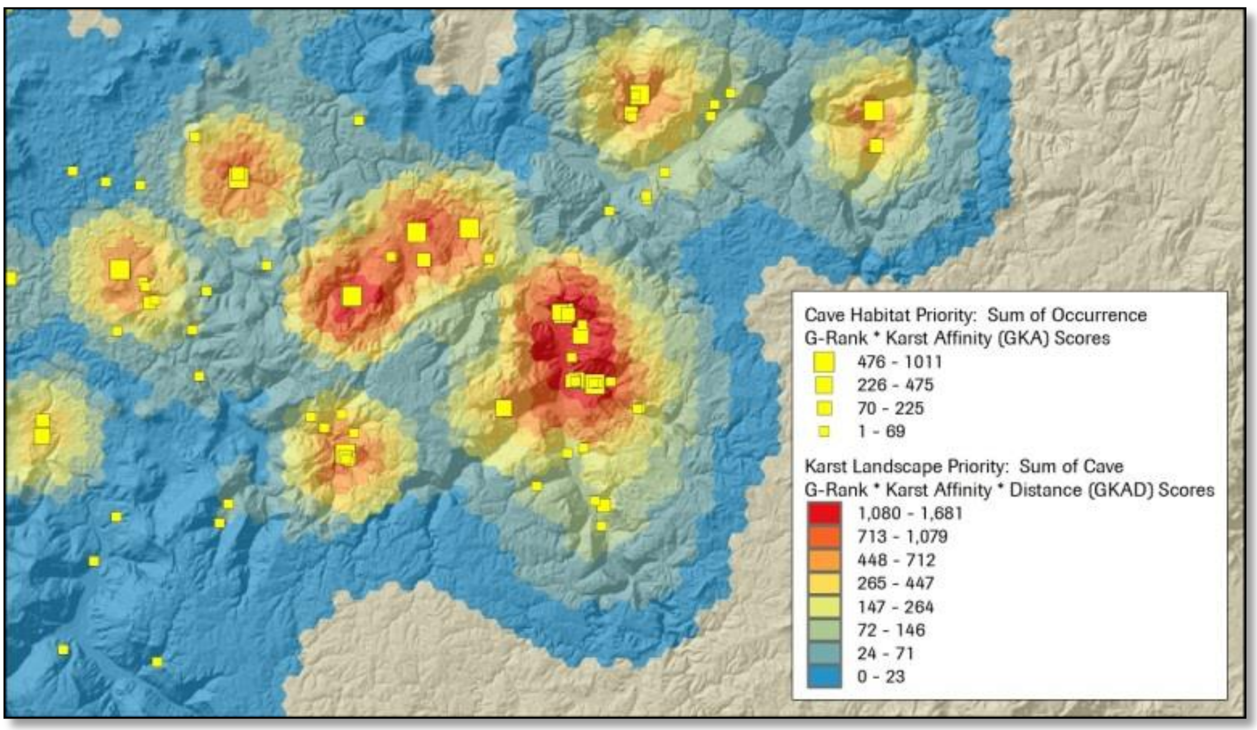

Figure 5. Illustration of cave location and surrounding karst landscape priorities based on the 100 acre hexagon scale.

Assessing Wetland Habitats

Another advancement in habitat mapping since the 2005 planning process has been to develop methods for identifying wetland habitats and the surrounding uplands which are providing important habitats for SWAP GCN animals and plant species. The Nature Conservancy developed this analysis during a collaborative planning effort with state and federal agencies, including TWRA, for the Stones River watershed in 2010 (Palmer and Wisby 2011).

The goal of the pilot effort on the Stones was to provide information on plant and animal habitat needs so that this conservation data may be better utilized during stream and wetland permit and mitigation plan reviews. The architecture of the GIS and relational database allowed the same analyses done for the Stones watershed to also be completed for all Tennessee's watersheds.

It is often not possible to explicitly map wetlands with useful accuracy in GIS. The limitations of existing GIS data on the location, condition, and types of wetlands - both existing historical -are well documented. National Wetlands Inventory (NWI) data are several decades old and have not been updated to reflect recent changes in land use and associated impacts to wetlands. Soils data (SSURGO) were also developed decades ago, and at the county level, resulting in very different classifications and hydric soil designations from county to county. With the exception of large, matrix-scale systems, wetland habitat classes tend to be underrepresented in satellite imagery-based classifications, such as SEGAP.

These shortcomings in identification and prioritization of wetland habitats were recognized in the initial development of Tennessee's SWAP in 2005. Since that time, using techniques developed as part of the Stones River planning effort, analyses have been conducted to prioritize areas based on *potential* wetland habitat function, essentially answering the question, "If a wetland is identified at a particular location, what would be its relative priority within the landscape?"

Priorities of potential wetland habitats for terrestrial species were assessed utilizing species-rosette footprints and data on preferences of species for wetland ecological systems contained in the SWAP database. Wetland ecological systems in Tennessee can be divided into 2 broad classes: linear systems closely affiliated with the riparian zone, and isolated small and large patch depression and seepage systems.

For isolated wetland classes not affiliated with the riparian zone, potential habitat priority was assessed and mapped to the terrestrial rosettes. For each rosette, the species assessments from the SWAP terrestrial model, rating species by imperilment (RL), viability (V), and relative distance from known occurrence (D), were additionally scored by their assessed preference for isolated wetland systems known to occur in the ecoregion, and the resulting RLVDP scores totaled for each rosette to give overall potential habitat priority for terrestrial species. Figure 6 provides an example of potential isolated seepage swamp habitat priorities in the East Gulf Coastal Plain based on the isolated wetland scoring formula.

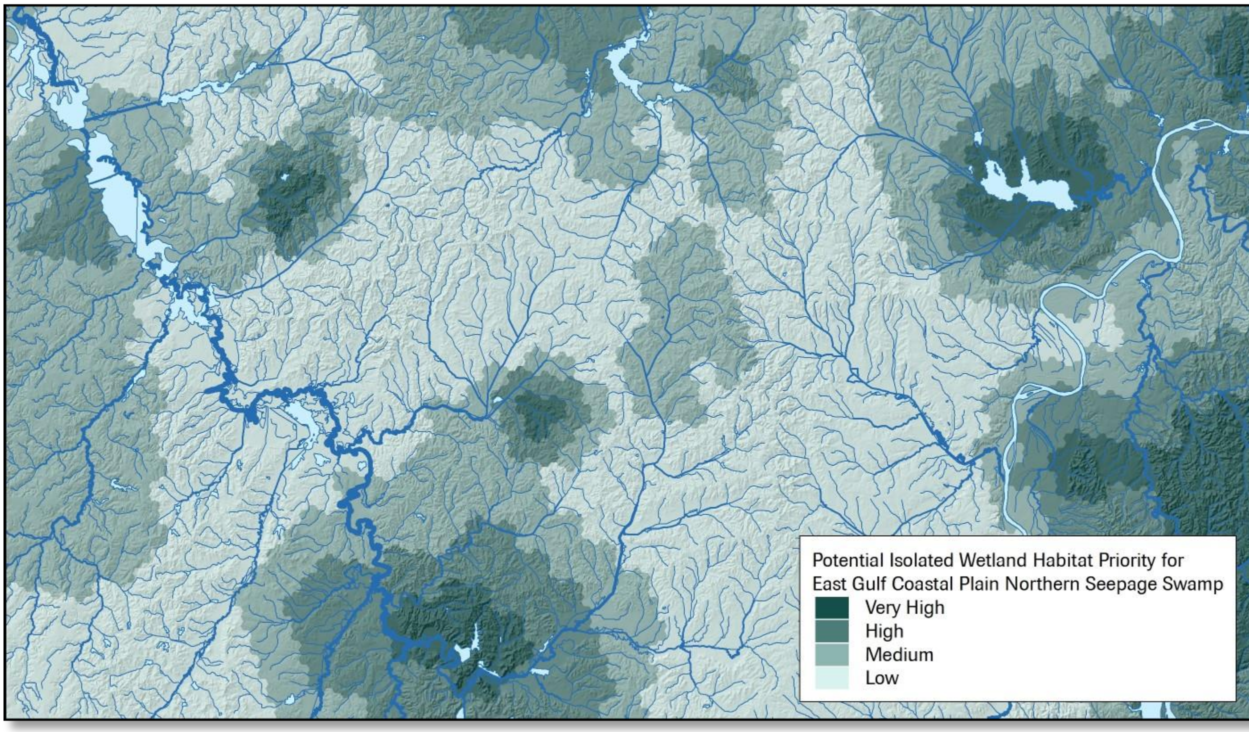

Figure 6. Example isolated wetland prioritization map showing potentially significant areas of East Gulf Coastal Plain Northern Seepage Swamps.

With a few notable exceptions, linear riparian wetland ecological systems fall into 2 classes: small stream and riparian systems, and large floodplain systems, that are then are differentiated to individual systems spatially by their ecoregion(s) of occurrence. These classes differ from each other in the frequency and duration of inundation, and subsequent lateral floodplain extent. Because of their tight association with hydrologic regimes, potential priorities for linear systems were assessed and mapped using the SWAP aquatic stream segment units of analysis.

Both classes of riparian systems were mapped in the 2001 GAP ecological system dataset, but are believed to be underrepresented in that coverage. Based on overlaying the GAP coverage with the catchments associated with aquatic stream segments, and correlating the relative amount of each class mapped in GAP with flow volumes of the stream segments, an arbitrary but reasonable cutoff flow value of 270 cfs was selected to differentiate between the classes.

To spatially correlate the terrestrial rosettes with the aquatic stream segments, the 2 layers were overlaid, and proportional stream segment lengths within intersecting rosettes were calculated. This allowed the species/rosette assessments (RLVD scores) from the terrestrial SWAP model to be linked to the aquatic stream segments. Similar to the assessment methodology for isolated wetlands, habitat preference scores for the appropriate riparian ecological system were also calculated. Species in riparian areas with flow less than 270 cubic feet per second (cfs) were assessed for the ecoregion-appropriate Small Stream and Riparian habitat preference, while species in streams with flows greater than 270 cfs were scored by their preference for the Large Floodplain system associated with the given ecoregion. As with the isolated wetland analysis, resulting RLVDP scores for individual species were totaled for each stream segment to give overall potential riparian habitat priority for terrestrial species.

As has been widely documented, intact and functional stream-side riparian buffers are very important to the health and condition of adjacent and downstream instream habitats. The SWAP aquatic model was therefore used to assess the relative priority of stream-sides by proximity, as a function of instream water travel time, and relative flow contribution, to prioritized aquatic habitats. These stream-side aquatic priorities were then added to the terrestrial riparian priorities, to give overall priority scores for riparian areas. Figure 7 illustrates the combination of both terrestrial and aquatic animal habitat priorities onto one map which highlights the significance of specific riparian habitat locations.

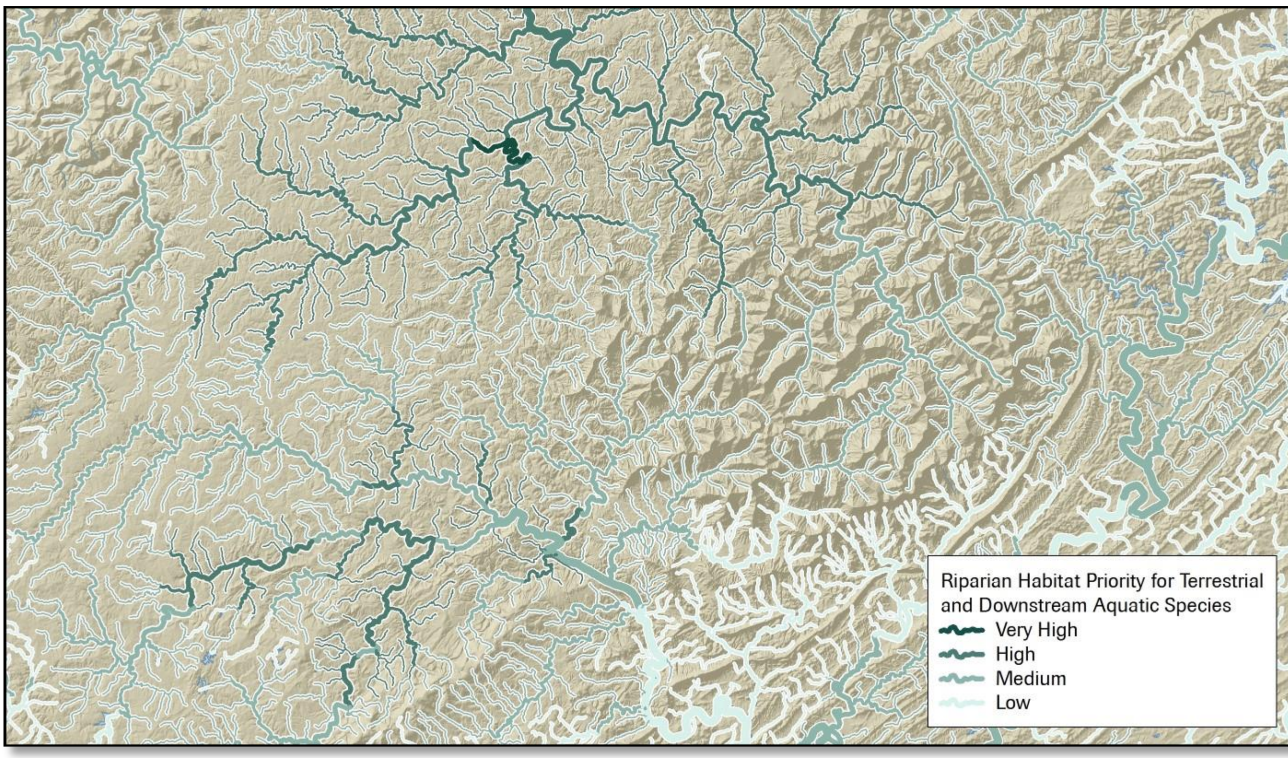

Figure 7. Example map of combination analysis using both terrestrial and aquatic priorities to identify significant regions of riparian wetland habitats.

SPATIAL IDENTIFICATION & ANALYSIS OF THREATS

Identifying problems affecting species and habitats is a primary requirement of all State Wildlife Action Plans. "Problems" are often described in two major components represented by direct or indirect ecologic stress and the sources of the ecological stress. "Sources" are commonly associated with major land and water uses in a region and other factors such as invasive species and disease.

Sources of stress to species and habitats were not explicitly mapped during the 2005 TN-SWAP planning process. Rather, a list of sources of stress was developed, and the SWAP planning team then rated these sources for various components of their perceived effects on GCN species, within a number of broad stress categories, in the various ecoregions of the state. The components rated include the percentage of populations believed to be affected, severity of stress, reversibility of stress, timing of stress (i.e. historic, current, or potential future stress), and contribution of the source of stress to other sources (TWRA 2005). While these ratings were useful in understanding what types of impacts may negatively affect GCN species, we did not have an understanding of where GCN species and sources of stress potentially co-occur on the landscape.

In the time since the 2005 SWAP planning effort, much work has been done to map and model both current and future sources of stress to species and habitats. Efforts thus far have also primarily focused on sources of stress to aquatic species and their habitats. However, much of the mapping and assessment work is relevant and directly applicable to terrestrial and subterranean habitats and species.

Mapping Urbanization

Population growth in certain regions of Tennessee has been at some of the highest rates in the nation for the past 20 years. Urban and suburban development related issues were identified in the 2005 TN-SWAP as highly ranked stressors to terrestrial, aquatic, and subterranean GCN species. Understanding the potential trajectory and spatial footprint of future development across Tennessee is critical to identifying habitat protection, restoration, and management needs. The Nature Conservancy designed an analysis approach for translating existing data on population growth, community growth plans, and potentially developable land.

To begin, a statewide development suitability model was constructed based on land cover type, topographic slope, Federal Emergency Management Agency flood ratings, land protection status, and accessibility to existing urban centers. The various components were classified and rated for their potential for future development, considering factors such as legal feasibility, practicality, and relative cost, into preferred, suitable, and marginal categories. These components were then overlaid, and final suitability based on the lowest (minimum) suitability rating among the component scores.

As part of their growth management plans required by the Tennessee Growth Policy Act of 1998, counties in Tennessee mapped future urban growth areas around existing municipalities, as well as planned growth areas within unincorporated portions of counties. These data were compiled and used to classify census blocks by their current and future growth planning status. The classified census blocks were then overlaid with the development suitability ratings, and used to allocate existing population within census blocks. In the resulting layer, areas of the state are mapped and attributed by their current population, existing and future growth planning class, and development potential.

The Tennessee Advisory Commission on Intergovernmental Relations (TACIR) and The University of Tennessee Center for Business and Economic Research (CBER) produce and publish population growth projections for Tennessee's 389 municipalities and unincorporated portions of counties at 5-year intervals. These data were compiled, and the projected changes in population were spatially allocated to the combined census block/growth planning/development suitability layer. The result is a spatially explicit projection of future population growth and distribution, at 5-year time steps, out to the year 2040.

Population densities were then calculated from the projections and, using a formula developed by the Greater Vancouver Sewerage and Drainage District and adopted by the Environmental Protection Agency, converted to estimates of percent total impervious area (%TIA). Percent TIA projections for the year 2040 were then subtracted from those for the year-2000 model baseline to give estimates of total projected change in Percent TIA.

To assess the relationship between future population growth and terrestrial habitat loss, a correlation analysis was conducted between the NLCD 2011 impervious surface coverage and the developed land classes in the NLCD 2011 landuse/landcover. Both coverages were overlaid with the terrestrial rosettes, and the results used to calculate percent impervious area and percent developed area for each rosette in the state. Rosettes were then grouped by 10ths of percent imperviousness, and average percent developed calculated for each percent impervousness bin. These averages were then smoothed to give a table of projected percent development for each given percent imperviousness value. Using this table, it was possible to estimate the area of terrestrial habitat that would be lost to development from the population growth model's projected increases in percent imperviousness.

Agriculture

Agricultural land use practices were assessed using the 2014 Cropland Data Layer prepared by the United States Department of Agriculture's (USDA) National Agricultural Statistics Service. Crop types in the Cropland Data Layer were rated for potential hazard to downstream aquatic systems on a 5-point scale, based on considerations such as amount, frequency, and type of nutrient, pesticide, and herbicide input, and potential for input and sediment runoff.

For use in the aquatic stress assessment, mapped crop types from the Cropland Data Layer were overlaid with the active river area/flood zones, and potential agricultural hazard scores weighted by location in various upland, floodplain, and material contribution zones.

Non-renewable Energy Development

For the assessment of potential oil and natural gas extraction impacts, point source datasets include the Tennessee Department of Environment and Conservation (TDEC) Water Pollution Control (WPC) permit database, as well as the Oil and Gas Well (OGW) permit database maintained by the TDEC Division of Geology. The WPC database contains location, issuance and expiration dates, and textual descriptions of numerous types of permitted activities. The OGW data were rated for potential hazard based on type of well, age, and time since plugged. To compensate for mapping inaccuracy and spatial uncertainty in location and extent of impacts, 359-meter buffers were generated around all point source locations, creating 100-acre 'footprints' of potential impact.

The TN Coal Mining Permit Boundaries dataset from the US Office of Surface Mining, obtained in October 2014, were used to assess sources related to coal resource extraction. These data include dates of permit retirement (if applicable), which were used to calculate age scores for each permit, indicating presumed time since active mining occurred at the site.

As with the agricultural assessment, the mapped mining permit areas were overlaid with the active river area/flood zones. Hazard scores were calculated based on permit age, weighted by location in various upland, floodplain, and material contribution zones.

Climate Change

As part of the overall TN-SWAP update process, terrestrial habitats across the state were assessed for potential climate change stress and resiliency using the US Forest Service Terrestrial Climate Stress Index (TCSI) and results of The Nature Conservancy's Resilient Sites for Terrestrial Conservation (Joyce and Flather 2015 and Anderson et al. 2014). These assessments take very different, but complementary approaches to examining potential effects of climate change on the landscape. The TCSI overlays coverages of major vegetation types with various temperature and precipitation change prediction models and scenarios, and then models the predicted response and potential change in vegetation type that may result. The results of the various responses are synthesized into an overall index of terrestrial climate stress to identify areas where vegetation types are more likely to change, as well as areas where they are predicted to be relatively stable given various scenarios of future climate change (Glick et al. 2015).

The Resilient Sites for Terrestrial Conservation approach maps and rates factors of a site's geophysical setting, topographic complexity, and permeability and connectedness to assess its overall capacity to "adapt to climate change while still maintaining diversity and ecological function" (Anderson et al. 2014). Thus, rather than predicting response to a specific climate change scenario, the resilient sites analysis aims to identify areas that are relatively more likely to continue to provide habitat and function, regardless of the nature and magnitude of future change in climatic factors.

Linking Sources of Stress to Habitats

To assess potential sources of stress to terrestrial GCN species, potential stress footprints were overlaid with terrestrial habitat patches. For subterranean species, rosettes in the potential nutrient input and aquatic recharge zones were overlaid with potential stress footprints. This allowed identification, mapping, and acreage summarization of areas of high priority and high potential stress, high priority and low potential stress, etc. To facilitate interpretation, stress and priority factors were each grouped into 3 classes, i.e. above average, average, and below average stress, and high to very high, medium, and low to very low habitat priority, and the combined 9 classes were mapped.

To assess potential stresses to aquatic GCN species and their habitats, results of the various stressor footprint analyses were overlaid with the NHDPlusV2 watershed catchments, and proportional area values calculated, resulting in area-weighted ratings of both current sources of stress and future change in percent impervious area, for each catchment. The hydrologic relationship data were then used to calculate a source of stress hazard score for each stream segment, based on values within each catchment comprising its overall watershed, weighted by mean annual travel time and percent flow contribution. For example, Figure 8 demonstrates potential for streams to be impacted by agricultural land uses within their watersheds if best management practices are not applied. Figure 9 illustrates areas of current and projected future impervious surface, and the projected total future impervious surface cover that would result in the watersheds of associated stream segments downstream.

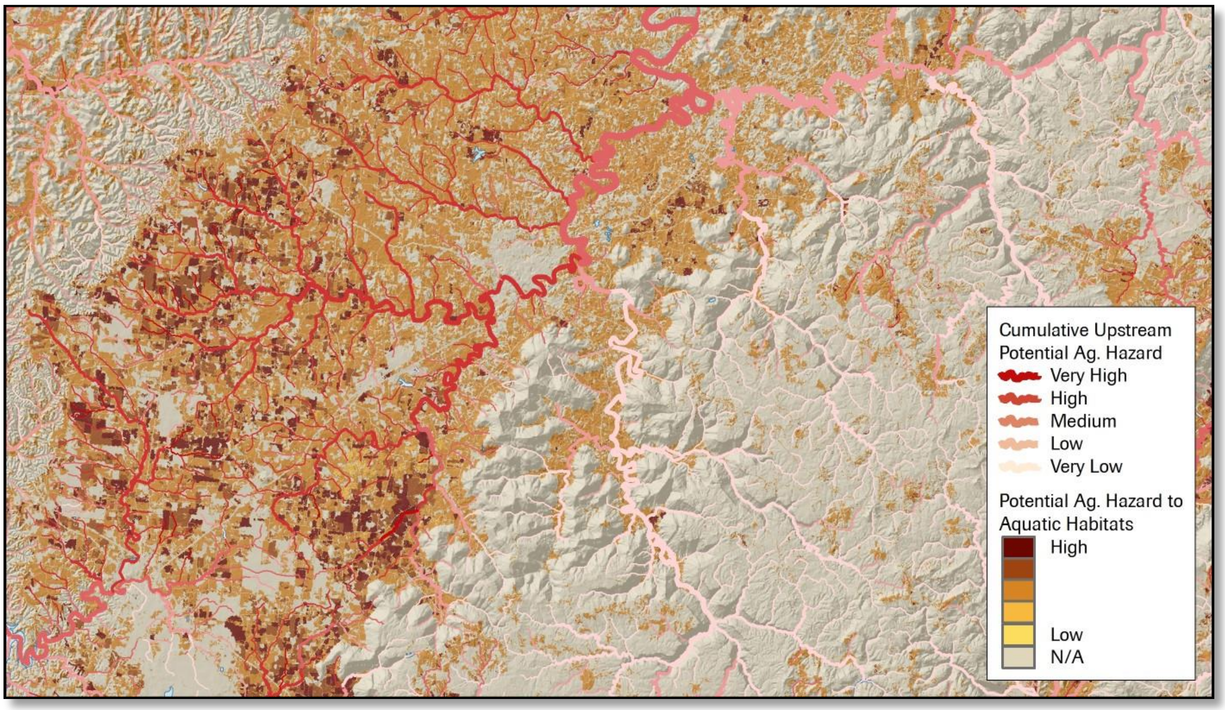

Figure 8. Example of potential hazards to instream habitats posed by agricultural land uses if best management practices are not applied on the landscape.

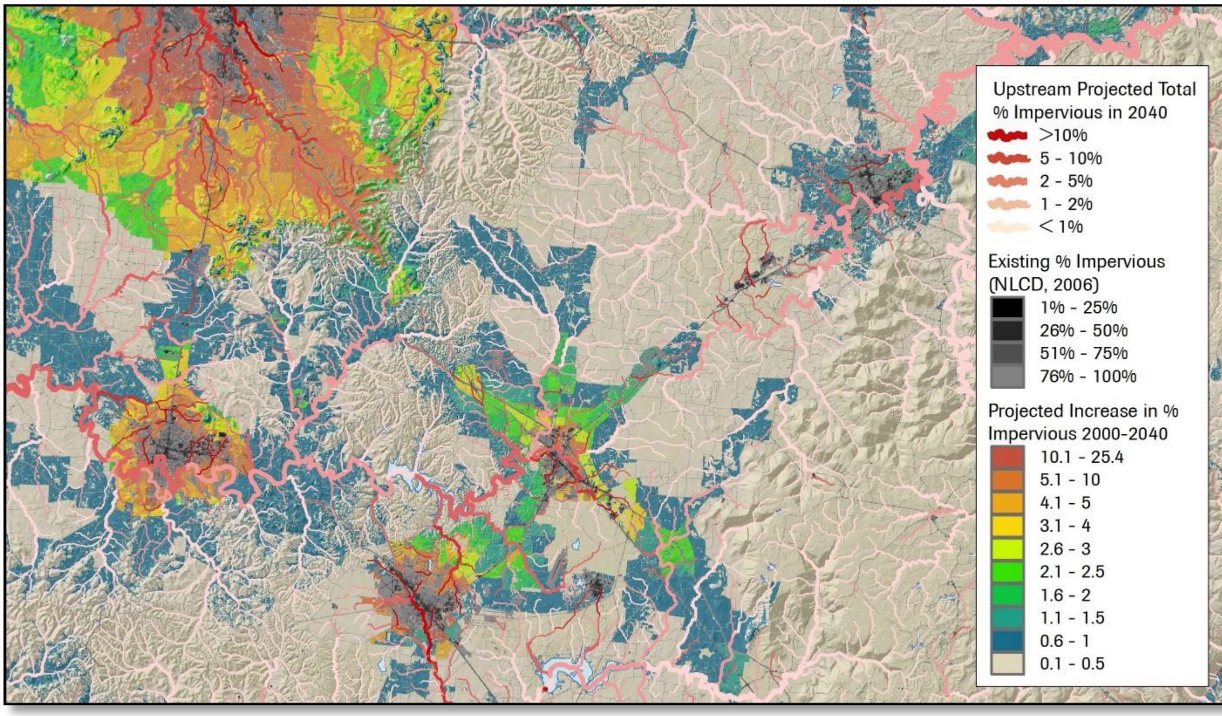

Figure 9. Example map showing the distributions of current and potential future impervious surfaces and the linkages to downstream habitats.

Next, hazard values for the stream segments were multiplied by their GCN habitat priority scores, resulting in a potential risk rating for stream segments from various sources of stress. Catchments upstream were then scored by total risk ratings of downstream habitats, weighted by habitat length, proximity (mean annual instream travel time), and percent watershed area. These values were then used to score and map areas of stress by their potential to lead to high downstream habitat risk.

Restoration

The terrestrial habitat prioritization model was also used to assess short- to medium-term restoration priorities for semi-natural habitats. As a first step, the natural vegetation types that could result from restoration at a site were identified and mapped, using the LANDFIRE 2012 Environmental Site Potential (ESP) coverage. This layer maps the vegetation that could be supported at a given site based on the biophysical environment, using the same NatureServe ecological system classification as utilized in the TN-SWAP modeling. The ESP layer was overlaid with existing semi-natural habitats from the terrestrial analysis unit coverage. Next, the preferences and scores of GCN species whose footprints overlap the semi-natural habitat sites for the restored habitats were used to calculate potential restored habitat priority scores for the sites. The existing semi-natural habitat priority scores were subtracted from those of the restored habitat, resulting in scores of net benefit to GCN species with occurrences in the area from restoration at the sites (Figure 10).

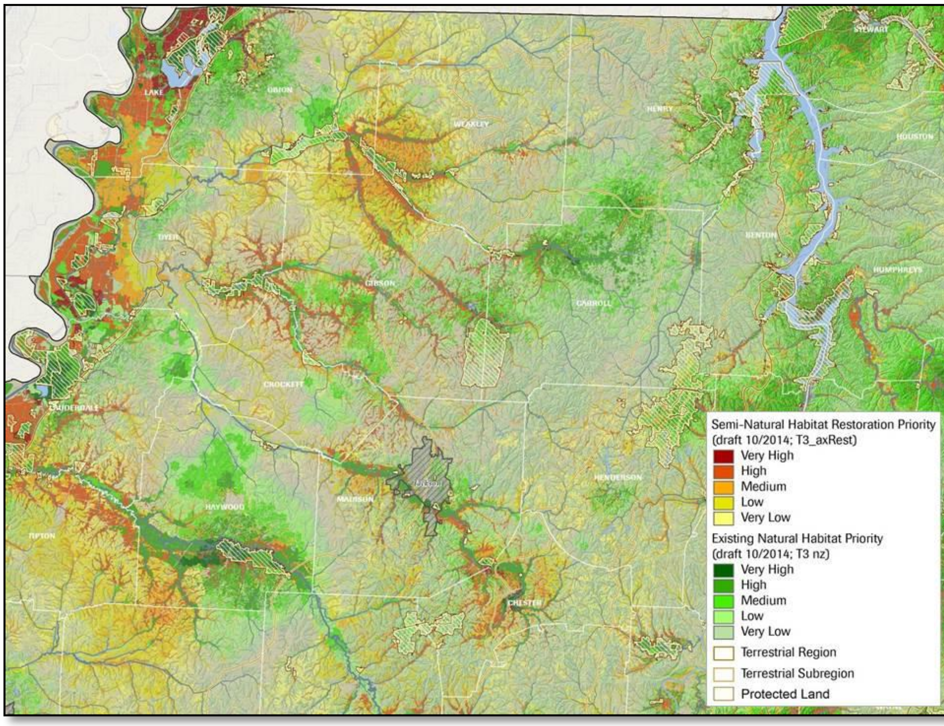

Figure10. Example map showing potential terrestrial restoration priorities in West Tennessee.

SUMMARY

This report provides a summary of the new data and analyses regarding GCN species and their habitats utilized during the 2015 State Wildlife Action Plan revision process for the state of Tennessee. The examples provided demonstrate several types of GIS outputs which can be used to inform conservation investment and land & water management decision-making. The architecture of the GIS and RDBMS system is flexible and allows for a wide variety of data inputs and prioritization formulas to be used. This flexibility ensures that as new data is available or new conservation issues arise, a data management and spatial analysis platform exists that can deliver outputs for new decision-making contexts. As compared to the data available during the 2005 SWAP planning, the updated information on species occurrences and spatial analyses of known sources of stress and major problems across Tennessee can help guide much more targeted investments to benefit plant and animal species statewide. The Nature Conservancy looks forward to continuing our work with TWRA and other partners to provide the most useful GIS and database outputs in support of future conservation planning and decision-making.

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