

ARE VERMONT'S RARE, THREATENED, AND ENDANGERED
SPECIES HABITATS ADEQUATELY PROTECTED?
A WATERSHED-SCALE ANALYSIS

by

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ABSTRACT

Vermont contains a wide range of forests, wetlands, and waterways that support many rare, threatened, and endangered (RTE) plant and animal species. As development, land-use change, and habitat fragmentation continue across the state, it is increasingly important to understand whether existing protected lands are sufficient to conserve these vulnerable species. My project addresses that problem by examining how well RTE species habitats align with Vermont's protected lands and identifying where conservation gaps remain. Because ecological conditions vary widely across the state, my analysis focuses on watershed-scale patterns to reveal local needs that may be hidden in statewide summaries. To evaluate the relationship between RTE habitats and protected lands, I compiled spatial datasets from state agencies that map RTE plant and animal habitats, watershed boundaries, and protected lands categorized by their level of long-term conservation. Using QGIS software, I intersected RTE habitat polygons, watershed boundaries, protected lands, and land-cover data to understand the dominant watersheds and landscape types associated with protected and unprotected habitats. I produced numerical tables for each watershed to compare patterns across the state. My results show that most RTE habitats in Vermont fall outside protected lands. Only about one-third of RTE animal habitats and less than one-third of RTE plant habitats occur within areas that have long-term conservation status. No watershed in the state protects a majority of its RTE plant habitats, and only a few protect more than half of their RTE animal habitats. Watersheds with the highest protection levels tend to contain large blocks of public land, while those with the lowest protection levels often include more private or agricultural landscapes. These findings suggest that Vermont's current protected-land network does not fully safeguard the habitats most important for RTE species. Watershed-specific patterns highlight where conservation efforts could be expanded to improve habitat connectivity, reduce fragmentation, and better support species persistence. Strengthening protections in under-represented watersheds will be essential for maintaining Vermont's biodiversity into the future.

INTRODUCTION

Overview of Vermont

The state of Vermont (VT), located in the northeastern United States, is home to 2.4 million hectares (ha) of biodiverse lands that provide habitat for numerous plants and animals, many of which are categorized as rare, threatened, and endangered (RTE) species (Agency of Natural Resources: Department of Forests, Parks and Recreation, 2026). Biodiversity encompasses the variety of plants, animals, and other living organisms within a habitat, which supports continuous, productive, and beneficial ecosystem function (Smithsonian National Museum of Natural History, 2026). Through the work of state and federal agencies, alongside local land trusts and non-profit organizations, approximately 448,000 ha of land have been designated as “protected” within the VT Protected Lands Database (VPLD) to help support VT’s biodiverse ecosystems (VT Center for Geographic Information, 2026). In this project, I provide a subwatershed-focused analysis and overview of VT’s habitat distribution for RTE plant and animal species, examining their relationship to existing protected lands and identifying priority areas that would benefit from additional conservation measures.

Protected Lands

Protected lands, also known as conserved lands, are areas that have been set aside for the preservation of land and its ecosystems. Within the VPLD dataset, each property has been assigned a USGS GAP Status code (1-4) to clarify varying degrees of protection (U.S. Geological Survey, 2026; VT Center for Geographic Information, 2026). GAP analysis can be

used for a variety of purposes including decision making, conservation planning, research, land management, and the prevention of habitat loss. As the worldwide population increases and infrastructure is built to support that growth, habitat preservation must become a priority to support wildlife and ensure long-term ecosystem health (U.S. Geological Survey, 2026).

Status 1 signifies the highest level of protection, meaning that the plot of land is permanently protected, and there is no interference with the land in the case of natural disturbance events. In addition, there is a management plan created to maintain natural ecosystem processes. Status 2 lands are protected areas managed for biodiversity, but unlike Status 1 lands, they involve management actions that may interfere with natural processes. This can include the suppression of wildfire or flooding. These areas carry permanent management protections and also require a management plan, but natural disturbance events are not fully allowed to proceed without intervention (U.S. Geological Survey, 2026).

Status 3 lands are, for the most part, protected from changes in natural land cover, but do allow activities such as low-intensity logging and off-road vehicle use; they also sometimes allow higher-intensity activities such as mining. Despite the allowance of these processes, Status 3 lands do grant protection of federally listed endangered and threatened species habitats. Status 4 lands do not hold any known protection and are not bound by management plans or restrictions to prevent changes or alterations of natural land cover. These lands are often private or under unknown management and are considered “unprotected” according to the Protected Areas Database of the United States (PAD-US) (U.S. Geological Survey, 2026).

Multi-State Comparison

Within VT's 2.4 million ha of land, roughly 448,000 ha, or 19% of the state, are documented as protected within the VT Protected Land Database (VT Center for Geographic Information, 2026). Compared to nearby states of similar size, including Maryland, New Hampshire and Massachusetts, Vermont falls short of both the total area and the overall percentage of protected lands. Maryland leads with about 776,000 ha preserved out of the state's 3.2 million ha, or ~24% (Maryland Department of Planning et al., 2026; Maryland State Archives, 2026). Approximately 748,000 ha of New Hampshire's 2.3 million ha of land are preserved, or ~33% (Society for the Protection of New Hampshire Forests, 2026; State of New Hampshire, 2026). Massachusetts holds 567,000 protected ha out of 2.7 million ha total, or ~21% (Executive Office of Energy and Environmental Affairs & Massachusetts Global Warming Solutions, 2022; United States Census Bureau, 2026).

Habitat modification and subsequent habitat loss have led to global declines in biodiversity (Hanski, 2011). Not only has habitat loss driven global reductions in wildlife population sizes, but it has also disrupted the reproductive success for many common and endangered species (Tufts University, 2020). The World Wildlife Foundation noted a 73% decline in global wildlife population sizes between 1970 and 2020, which directly impacts the function of ecosystems and calls into question their ability to remain resilient in times of climate uncertainty (Fallah, 2024). A Tufts University study covering habitat loss from 1986 to 2018 documented trends of minimal reduction (3.6%) on federally protected lands, but significant habitat loss (8.6%) on private lands that lacked protections and management plans. Similar rates of habitat loss were found between lands protected by the state (4.6%) and non-governmental

organizations (4.5%), slightly less protected than federal lands, but significantly more than private unregulated lands (Tufts University, 2020).

Ecosystem management relies on understanding the geography, land potential, current habitats, property ownership, and existing protections to be effective (Montgomery et al., 1995). By looking at statewide and/or extensive subwatershed data, certain areas may be overlooked, but subwatershed-level assessments can help reveal localized patterns, stressors, and resource needs that broader analyses may miss (Regional Interagency Executive Committee & Intergovernmental Advisory Committee, 1995). The data within my project have been divided by VT's 8-digit HU subbasins to pinpoint where habitat protection gaps exist, reveal patterns of ecological vulnerability, and guide future land-protection efforts toward the areas where they will have the greatest impact (Vermont Agency of Natural Resources, 2025).

Subwatershed Scale Analysis

Subwatershed-scale analysis focuses on ecosystems and habitats at a relatively fine scale and can lead to a better understanding of the needs of specific regions, habitats, and communities (Montgomery et al., 1995). The Chesapeake Bay Watershed, for example, covers over 16.5 million ha and is fed by more than 100,000 waterways, both small and large. Efforts to study the overall water quality benefits of agricultural conservation practices within the watershed are difficult due to the large size and varying landscapes. To combat this, USGS researchers identified five small subwatersheds (between ~2,300 ha and ~3,300 ha) within the Chesapeake Bay Watershed that contain extensive existing conservation practices. The goal of their project is to identify post-conservation water quality trends within small-scale subwatersheds, while also

engaging communities, educating the public, and developing new insights and practices for larger-scale conservation implementation (U.S. Geological Survey, 2024). A highly specified location allows land managers, policymakers, and researchers to identify potentially vulnerable habitats, prioritize restoration efforts, and tailor conservation strategies to the unique ecological and social conditions of each subwatershed.

The datasets from the VT Fish and Wildlife Department and the VT Center for Geographic Information offer valuable insight into the distribution of RTE and uncommon habitats across VT's protected lands. By integrating data on RTE species, protected areas, and land cover, my project will help identify gaps in current protections and highlight priority areas for future conservation efforts (Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026). This will ultimately aid in prioritizing landscapes that sustain RTE species, ensuring that conservation efforts are both strategic and ecologically meaningful moving forward.

For my project, I hypothesize that the majority of RTE species' habitats fall outside of conserved lands or in areas with fewer environmental protections. Previous studies note that biodiversity loss in the United States is associated with several factors, including construction and development, a reduction of conservation practices, and an overall lack of federal, state, and privately preserved lands (Clancy et al., 2020; Tufts University, 2020; U.S. Department of Agriculture & U.S. Forest Service, 2016; Watson, 2018). I anticipate that my project will reinforce the need for more intentional, biodiversity-driven conservation planning across VT to protect vulnerable species populations. Conservation efforts not only prevent further land

degradation but also efficiently safeguard the places where biodiversity is highest, making conserved lands central to long-term ecological resilience.

METHODOLOGY

Initial Data Collection

To initiate this project, I compiled a series of spatial datasets from the VT Open Geodata Portal that represented the state's RTE plant and animal habitats, 8-digit HU subwatersheds, the state boundary, and protected lands classified by GAP status. All datasets were transformed to the common coordinate reference system (CRS) "EPSG:32145 - NAD83 / Vermont," to ensure spatial consistency (State of Vermont, 2026).

The primary dataset I used, "VT Rare, Threatened, and Endangered Species (Public)," is regularly maintained and updated by the Natural Heritage Program within the VT Fish and Wildlife Department under the Agency of Natural Resources. This dataset contains 6,956 current records documenting the distribution of RTE plant and animal habitats across the state. It is important to note that variation in mapped habitat size may be influenced by the inclusion of uncertainty buffers rather than differences in actual habitat extent. For consistency across the analysis, the total hectares (ha) associated with each recorded habitat were summed to generate an overall estimate of RTE habitat area. Because the dataset incorporates uncertainty buffers around some habitat features, these totals may overrepresent the true extent of the underlying habitats. The original dataset falls within CRS: "NAD83 / Vermont" (Vermont Fish & Wildlife Department, 2025).

The primary RTE dataset was analyzed in conjunction with the VT Protected Lands Database, developed by the VT Center for Geographic Information and is updated quarterly. The dataset includes 13,802 parcels divided by GAP-Status codes 1-4, but for my project, only the polygons for lands with GAP Status 1-3 were counted. GAP Status 4 lands lack any known

public or private land-use protection, so their inclusion would be misleading. The original dataset falls within CRS: “NAD83 / Vermont” (VT Center for Geographic Information, 2026).

After downloading both the RTE habitat data and the protected lands data, I separated the attributes by subwatershed. I utilized the VT state boundary shapefile and overlaid that on top of the “Watershed Boundary Dataset 8-Digit HU (Subbasin) Vermont” shapefile (Vermont Agency of Natural Resources, 2025; VT Center for Geographic Information, 2026). Before trimming down to solely include areas within VT, the subbasin dataset spanned segments of New York, Massachusetts, New Hampshire, and into Canada. While the state of VT shapefile resided within CRS: “NAD83 / Vermont,” the subwatershed boundary resided within “EPSG:3857 - WGS 84 / Pseudo-Mercator.” As stated previously, to ensure uniformity and proper spatial projections, all the layers were transformed to reside within CRS: “EPSG:32145 - NAD83 / Vermont.”

QGIS Data Mapping

I conducted all mapping and geographic analysis in QGIS 3.40 Bratislava long-term release (LTR) software. I imported all previously mentioned layers into QGIS and clipped each layer to the VT state boundary. I then intersected the “Watershed Boundary Dataset 8-Digit HU (Subbasin) Vermont” layer and the state boundary shapefile, so only VT’s 18 subwatersheds remained. These subwatersheds serve as the geographic foundation for my project, allowing for the RTE habitat and protected lands data to be broken down by uniform location (Figure 1).

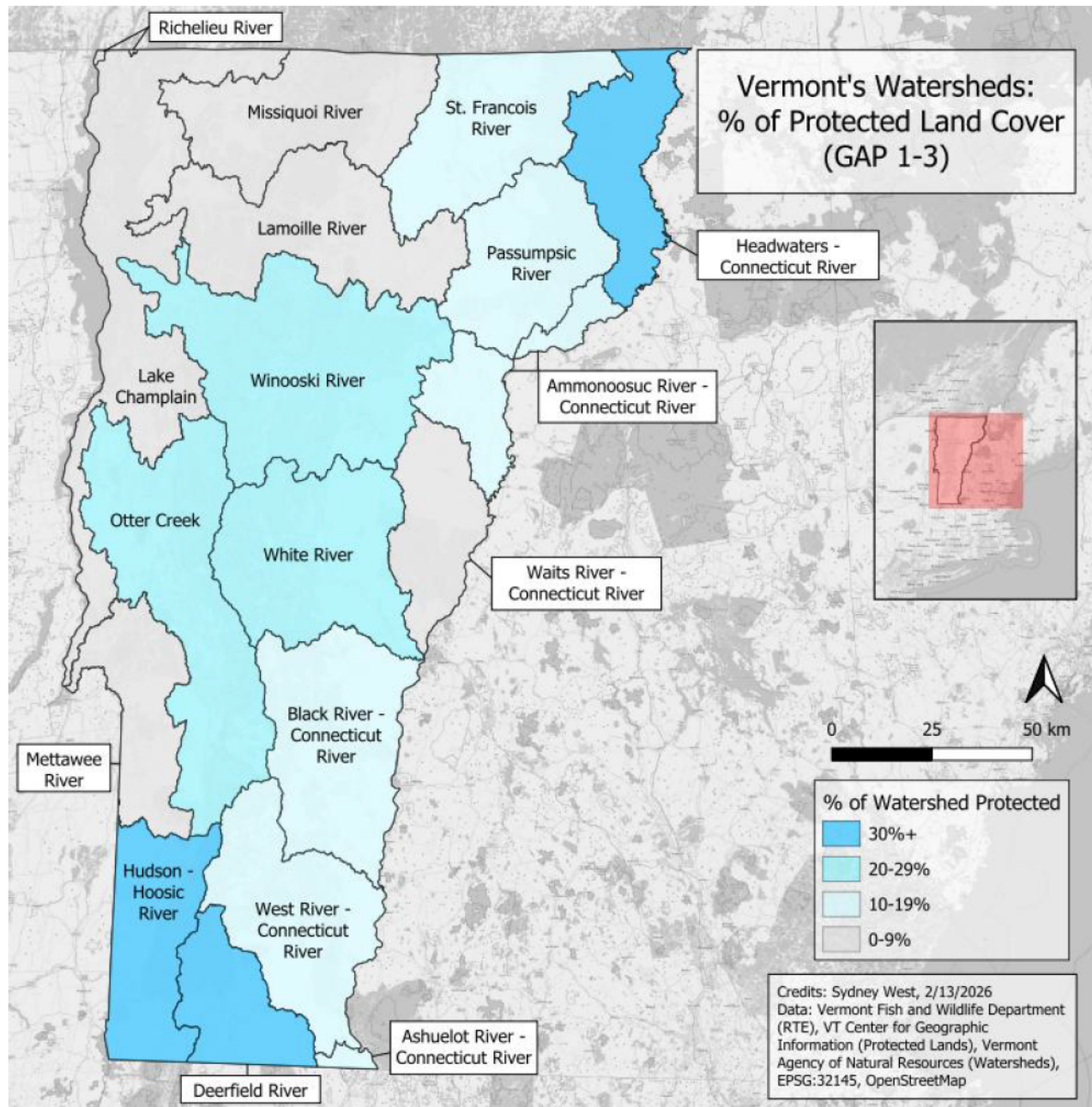


Figure 1. Vermont's subwatersheds and the percentages of protected land within each.

Once I corrected each layer's geometry, I separated and cleaned the RTE layer by GAP Status, ensuring each area of land was assigned only one GAP code. Several overlapping polygons were assigned different protection statuses, leading to many areas being double-

counted and skewing the overall data. To solve this, I completed a hierarchal subtraction that prioritized GAP 1 > GAP 2 > GAP 3 > GAP 4. After assigning each land parcel a single GAP Status code, I calculated the total protected area (ha) for each GAP category and intersected the layer with VT's subwatersheds. This assigned each parcel of protected land a unique subwatershed value.

As stated previously, my project aims to synthesize the presence of RTE habitats that fall within protected lands. To visualize this, I separated the RTE habitats into those that fell within and those outside of GAP Status 1-3 lands. The original RTE habitats have lower opacity and lighter colors, while the protected habitats have full opacity and darker colors (Figure 2). This distinction is simply to help visualize which areas have concentrated protected habitats and where areas of protection could be implemented in the future.

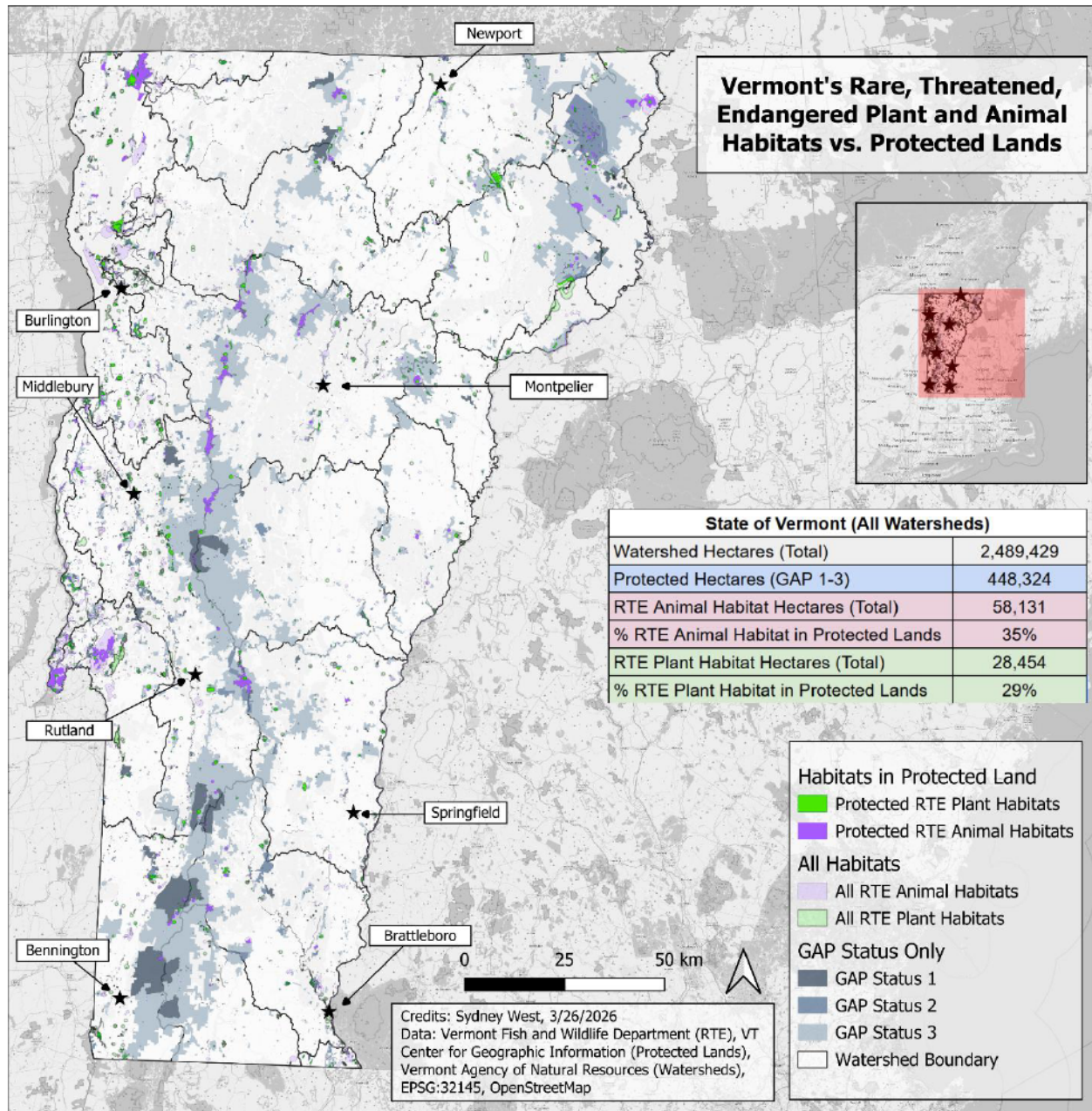


Figure 2. Full map of Vermont and its GAP Status 1-3 lands and RTE plants and animals.

Land Cover Analysis

I first downloaded 2024 NLCD data for the extent of Vermont using the Multi-Resolution Land Characteristics Consortium Viewer. When reprojecting the original layer CRS (WGS84) to the project CRS (EPSG:32145 - NAD83 / Vermont), the raster image was drastically relocated. Because of this relocation and the original CRS being geographically accurate to VT's boundaries, I chose to retain the layer's original projection (WGS84). I used the tool "*Clip Raster by Mask Layer*" to narrow the raster image to Vermont's state boundary.

I used the *Polygonize (raster to vector)* tool to convert the NLCD raster into a vector layer, resulting in 1,094,565 individual polygons, one for each raster pixel. I then used the *Dissolve* tool to simplify the vectorized NLCD vector by land cover type and was left with 15 multipart polygons. To match the original raster's color scheme, I located the webpage "National Land Cover Database Class Legend and Description," set the layer's symbology to "Categorized," and set the value to the land cover type. I then used "Classify" to create value-specific colors and adjusted the colors and legend titles to match the NLCD classification system (Multi-Resolution Land Characterization Consortium, 2024) (Figure 3). Following the vectorization of the land cover data, I used the *Intersect* tool to distinguish land cover types by subwatershed boundary.

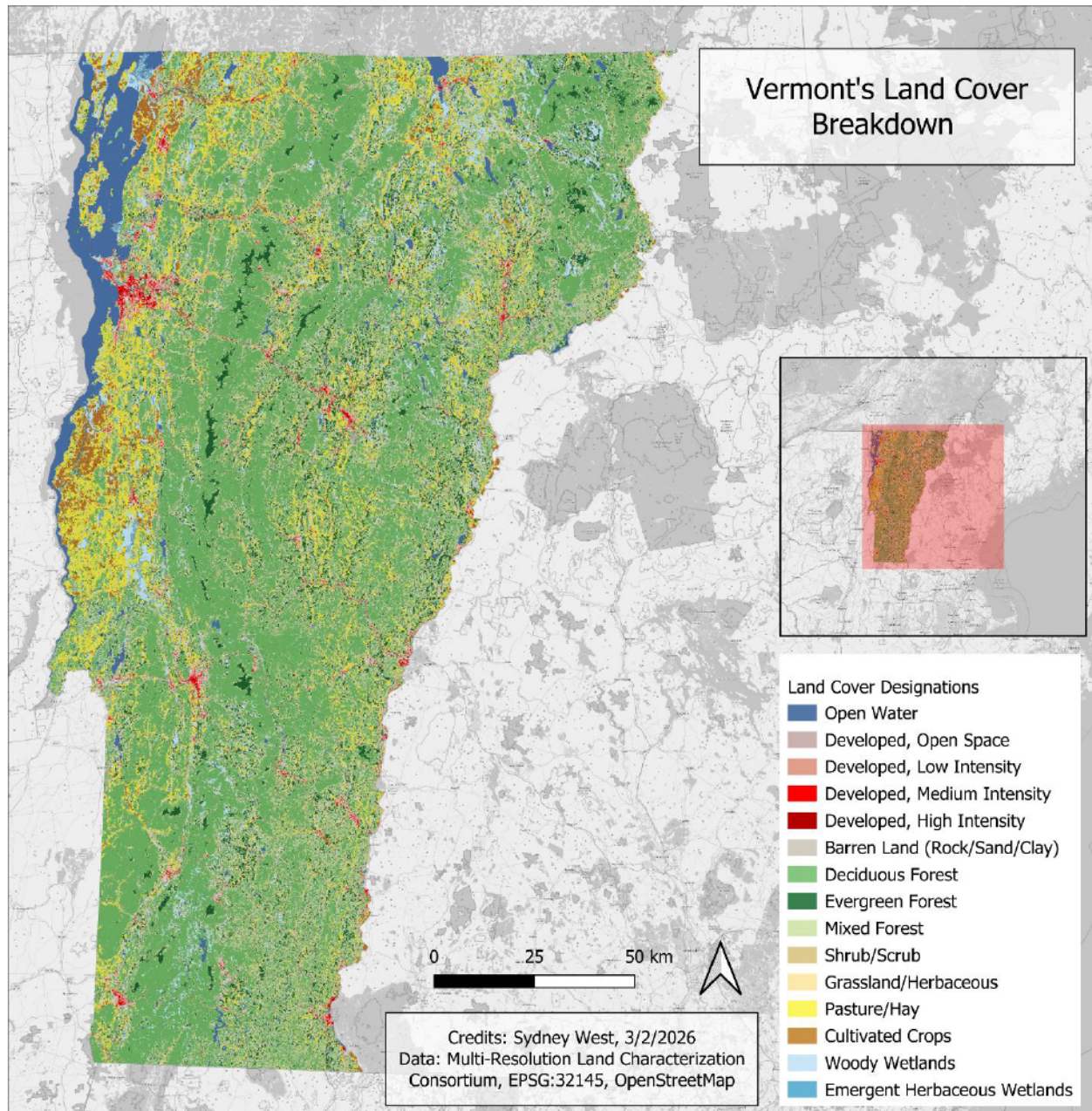


Figure 3. Vermont's National Land Cover Database (NLCD) designations.

Numerical Analysis and Table Creation

RTE Habitats and Protected Lands

I used Microsoft Excel to calculate percentages of habitats and land protected, create tables for final maps, and organize the area of both RTE plants and animals by GAP Status. While creating the maps for this project, I found it helpful to include small data tables that capture only the area being studied. While the larger data table helped view the data and visualize the subwatersheds in comparison, the smaller data tables helped contextualize the individual subwatershed maps and the scope of subwatershed-specific protections.

Land Cover

To find the land-cover breakdown by subwatershed, I used the *Polygonize (Raster to Vector)* and *Intersection tools* to create multipart polygons by land-cover type across VT, intersecting the layer with RTE plant and animal habitats. I ran these tools and then intersected the output layer with the clipped subwatersheds to provide me with a breakdown of protected RTE plant and animal habitats by land-cover type, per subwatershed. I repeated this process for the original RTE plant and animal habitats and then protected RTE plant and animal habitats. Within each individual subwatershed, I calculated the percentages of each land cover type by dividing by the total subwatershed ha. I did the same for the state of Vermont to identify the majority land cover types statewide and how they intersect with RTE plant and animal habitats.

RESULTS

Statewide/Watershed Size Data

The state of VT covers nearly 2.4 million ha across 18 subwatershed basins. The subwatersheds vary greatly in size, with the smallest (Richelieu River) holding only 915 ha within VT's boundaries and the largest (Winooski River) covering 275,317 ha. On average, the subwatersheds cover 138,302 ha, with a median of 141,476 ha. Of those 2.4 million ha of land, only 482,925 ha hold GAP Status code 1-3 designations. GAP Status 1 accounts for 58,951 ha of land, GAP Status 2 for 39,745 ha, and GAP Status 3 for 384,229 ha. Although GAP Status 4 encompasses a significant area (upwards of 169,000 ha), this land is excluded from the protected area totals due to the lack of official protection (VT Center for Geographic Information, 2026).

RTE Plant Habitats

Across VT, RTE plant habitats amount to 28,454 ha, or 1.14% of the total land area. Of those 28,454 ha of habitat, 8,129 ha (~29% of the total habitat acres) fall into GAP 1-3 protected lands. Most subwatersheds contain between 0% and 29% of total RTE plant habitats in protected lands, with only one in the 30%-39 % range and the remaining five in the 40%-49% range (Table 1). Throughout the state, no subwatershed exceeds 50% protection for RTE plants (Table 1, Figure 1) (Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Table 1. VT subwatersheds and their percentage of protected RTE plant habitats (Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Total % of RTE Plants in GAP 1-3 Lands	Subwatersheds and % of RTE Plant Habitats in Protected Lands
40-49%	- Headwaters - Connecticut River (49%) - Lamoille River (42%) - Otter Creek (41%) - Missisquoi River (41%) - Winooski River (40%)
30-39%	- Lake Champlain (33%)
20-29%	- Passumpsic River (28%) - White River (24%) - Black River - Connecticut River (23%) - St. Francois River (21%) - Hudson-Hoosic River (20%) - West River - Connecticut River (20%)
0-19%	- Ashuelot River - Connecticut River (17%) - Waits River - Connecticut River (17%) - Ammonoosuc River - Connecticut River (16%) - Deerfield River (15%) - Mettawee River (15%) - Richelieu River (0%)

RTE Animal Habitats:

Vermont contains significantly more ha of RTE animal habitats than RTE plant habitats. RTE animal habitats cover 58,131 ha, but only 20,526 ha, or 35% of the habitats, fall within GAP 1-3 lands. The majority of subwatersheds host between 0% and 39% of their RTE animal habitats in protected areas, with five subwatersheds exceeding 40% (Table 2). The subwatersheds with the highest protection, by a significant margin, are the Headwaters - Connecticut River (71%) and the Passumpsic River (64%) (Table 2) (Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Table 2. VT subwatersheds and the percentage of protected RTE animal habitats (Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Total % of RTE Animal Habitats in GAP 1-3 Lands	Subwatersheds and % of RTE Animal Habitats in Protected Lands
50% or higher	- Headwaters - Connecticut River (71%) - Passumpsic River (64%) - Ammonoosuc River - Connecticut River (55%) - Winooski River (51%)
40-49%	- White River (42%)
30-39%	- Otter Creek (37%) - Lamoille River (37%) - Hudson - Hoosic River (31%) - Missisquoi River (30%) - Mettawee River (30%) - Lake Champlain (30%)
20-29%	- Black River - Connecticut River (29%) - Deerfield River (26%) - West River - Connecticut River (24%) - Waits River - Connecticut River (20%)
0-19%	- St. Francois River (17%) - Ashuelot River - Connecticut River (6%) - Richelieu River (0%)

Land Cover

Vermont's land cover is dominated by deciduous (~39%) and mixed forests (~22%), but the abundance of these forests varies among subwatersheds. Most subwatersheds have between ~14% to ~66% deciduous forest coverage and ~8% to ~43% mixed forest coverage. The remaining land cover types, and their percentages of full state cover are as follows: Pasture/Hay (11.4%); Evergreen Forest (8.2%); Woody Wetlands (5.8%); Developed, Open Space (3.9%); Open Water (3.8%); Developed, Low Intensity (1.9%); Cultivated Crops (1.8%); Emergent Herbaceous Wetlands (0.7%); Shrub/Scrub (0.6%); Developed, Medium Intensity (0.6%),

Grassland/Herbaceous (0.3%); Barren Land (Rock/Sand/Clay) (0.3%); and Developed, High Intensity (0.1%) (Figure 4) (Multi-Resolution Land Characterization Consortium, 2024).

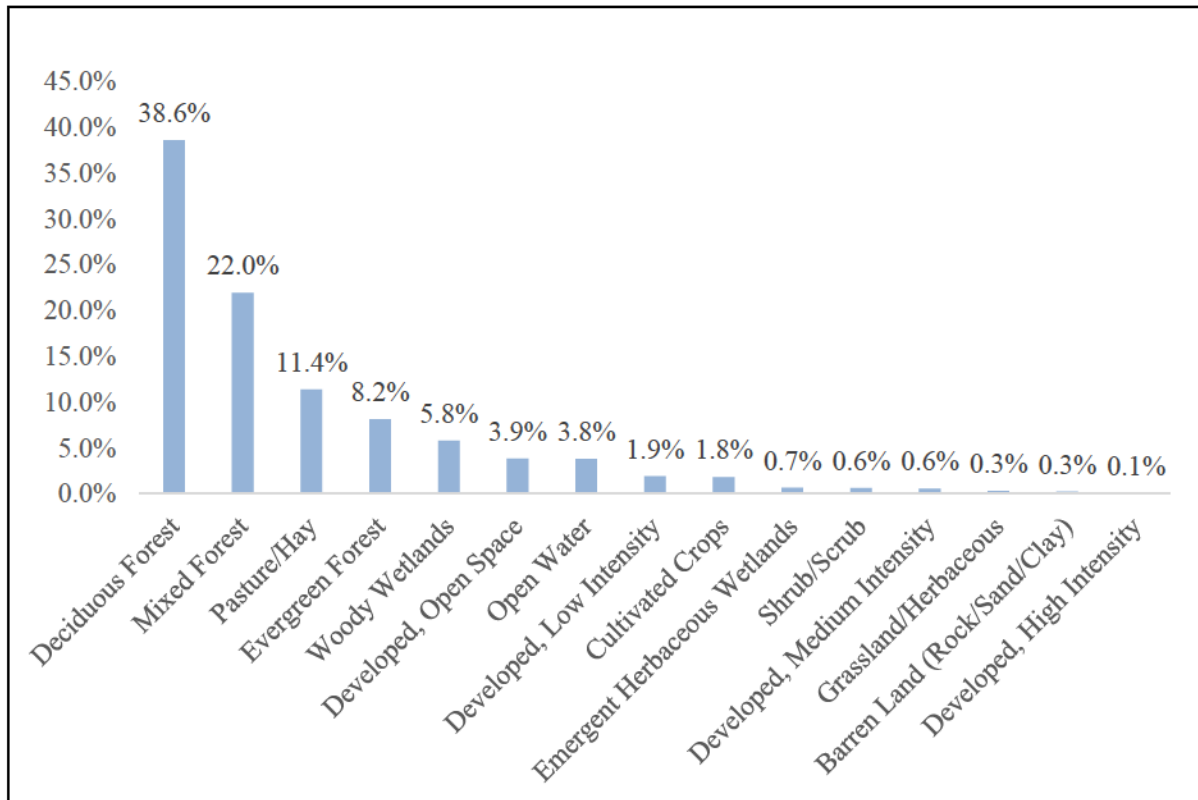


Figure 4. Percentage overview of VT's land cover types (Multi-Resolution Land Characterization Consortium, 2024).

Subwatershed Specific Plant RTE Habitats

Protected Plant Habitats (Inside of GAP 1-3 Boundaries)

Of the 8,215 ha of protected RTE plant habitats, the analysis shows that the majority of protected RTE plant habitats are concentrated in a small number of subwatersheds (see Appendices A and B for subwatershed maps). The largest concentration of protected RTE plant habitats falls within the Lake Champlain subwatershed (1,804 ha) (Figure A1) with Otter Creek

(1,498 ha) (Figure B1), Winooski River (827 ha) (Figure A2), St. Francois River (553 ha) (Figure A3) and Lamoille River (527 ha) (Figure A4) following closely behind. The remaining subwatersheds all contained between 0 ha and 469 ha of protected plant habitats. Across VT, the majority of protected RTE plant habitats occurred within forested lands (including deciduous, evergreen, and mixed) (54%) and wetlands (including emergent herbaceous wetlands and woody wetlands) (33%). In addition, these protected plant habitats also fell into lands designated as open water (8%), agricultural/grass areas (2%), and developed (including low, medium, high, and open developed) (1%) (Multi-Resolution Land Characterization Consortium, 2024; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Unprotected Plant Habitats (Outside of GAP 1-3 Boundaries)

The total area of unprotected RTE plant habitats is significantly higher than those that fall into GAP 1-3 lands. Compared to the 8,215 ha of protected habitats, 20,222 ha of RTE plant habitats remain unprotected. Most of these unprotected habitats fall within Lake Champlain (3,507 ha) (Figure A1), Mettawee River (2,532 ha) (Figure B2), Otter Creek (Figure B1), St. Francois River (2,120 ha) (Map A3), Hudson-Hoosic (1,456 ha) (Figure B3), and Ammonoosuc River-Connecticut River (1,438 ha) (Figure A5). The majority of unprotected plant habitats occur within forested lands (~41%) and open water areas (~29%). In addition, ~15% are located within wetlands (emergent herbaceous and woody), ~8% in developed lands, and ~7% in agricultural/grass areas. The remaining habitats were scattered throughout other land use types, but those habitats did not contribute to a large portion of the data (Table 3) (Multi-Resolution Land Characterization Consortium, 2024; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Table 3. Primary Land-Cover Types in VT's Subwatersheds Supporting RTE Plant Habitats (Multi-Resolution Land Characterization Consortium, 2024; Vermont Agency of Natural Resources, 2025; Vermont Fish & Wildlife Department, 2025).

Subwatershed:	Protected Plant Habitats: (Inside GAP 1-3 Lands)	Unprotected Plant Habitats (Outside GAP 1-3 Lands)
Ammonoosuc River- Connecticut River	Forest (52%)	Forest (83%)
Ashuelot River- Connecticut River	Open Water (29%) Forest (29%)	Forest (41%)
Black River-Connecticut River	Forest (71%)	Forest (52%)
Deerfield River	Wetlands (62%)	Open Water (58%)
Headwaters Connecticut River	Wetlands (40%) Forest (32%)	Open Water (80%)
Hudson-Hoosic	Forest (77%)	Forest (62%)
Lake Champlain	Wetlands (62%)	Forest (31%) Open Water (29%)
Lamoille River	Wetlands (63%)	Forest (41%)
Mettawee River	Forest (74%)	Open Water (55%)
Missisquoi River	Forest (67%)	Forest (58%)
Otter Creek	Forest (69%)	Wetlands (43%) Forest (41%)
Passumpsic River	Forest (80%)	Forest (62%)
St. Francois River	Forest (62%)	Open Water (74%)
Waits River-Connecticut River	Forest (73%)	Forest (51%)

Table 3 Continued.

Subwatershed:	Protected Plant Habitats: (Inside GAP 1-3 Lands)	Unprotected Plant Habitats (Outside GAP 1-3 Lands)
West River-Connecticut River	Forest (56%) Open Water (30%)	Forest (45%)
White River	Forest (60%)	Forest (58%)
Winooski River	Forest (66%)	Forest (42%)

Subwatershed Specific Animal RTE Habitats

Protected Animal Habitats (Inside of GAP 1-3 Boundaries)

Compared to protected RTE plant habitats, protected RTE animal habitats covered significantly more ha of land (20,542 ha compared to 8,215 ha), but they were also highly concentrated by subwatershed. Most protected animal habitats were found within Lake Champlain (5,272 ha) (Figure A1), Winooski River (2,783 ha) (Figure A2), Mettawee River (2,656 ha) (Figure B2), Headwaters Connecticut River (2,632 ha), and Otter Creek (2,607 ha) (Figure B4). On average, ~65% of those protected animal habitats fell within forested lands, with ~26% falling within wetlands, and the remaining habitats spread in smaller shares across agriculture/grassland (~4%), open water (~3%), and developed lands (<1%) (Multi-Resolution Land Characterization Consortium, 2024; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Unprotected Animal Habitats (Outside of GAP 1-3 Boundaries)

Approximately 37,621 ha of RTE animal habitats fell outside of protected GAP 1-3 lands, the majority of which were concentrated in Lake Champlain (12,584 ha) (Figure A1),

Mettawee River (6,327 ha) (Figure B2), Otter Creek (4,361 ha) (Figure B1), and Winooski River (2,629 ha) (Figure A2). These unprotected areas predominantly lie within forested (~34%) and open water (24%) areas, with a substantial amount found in agricultural/grassland areas (~21%). Smaller shares fell within wetlands (~10%) and developed lands (~10%), with the least amount (~1%) falling within shrub/scrub and barren covers (Table 4) (Multi-Resolution Land Characterization Consortium, 2024; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Table 4. Primary Land-Cover Types in Subwatersheds Supporting RTE Animal Habitats (Multi-Resolution Land Characterization Consortium, 2024; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Subwatersheds:	Protected Animal Habitats: (Inside GAP 1-3 Lands)	Unprotected Animal Habitats (Outside GAP 1-3 Lands)
Ammonoosuc River- Connecticut River	Forest (65%)	Forest (60%)
Ashuelot River-Connecticut River	Forest (37%) Wetland (32%)	Forests (55%)
Black River-Connecticut River	Forest (93%)	Forest (56%)
Deerfield River	Forest (94%)	Forest (68%)
Headwaters Connecticut River	Forest (72%)	Forest (92%)
Hudson-Hoosic	Forest (69%)	Forest (46%)
Lake Champlain	Wetlands (67%)	Open Water (47%)
Lamoille River	Forest (78%)	Forest (32%) Open Water (31%)
Mettawee River	Forest (79%)	Forest (52%)

Table 4 Continued.

Subwatersheds:	Protected Animal Habitats: (Inside GAP 1-3 Lands)	Unprotected Animal Habitats (Outside GAP 1-3 Lands)
Missisquoi River	Forest (88%)	Open Water (33%)
Otter Creek	Forest (81%)	Agriculture (43%)
Passumpsic River	Forest (74%)	Mixed Forest (43%)
St. Francois River	Forest (48%)	Open Water (64%)
Waits River-Connecticut River	Forest (78%)	Forest (62%)
West River-Connecticut River	Forest (85%)	Forest (52%)
White River	Forest (95%)	Forest (49%)
Winooski River	Forest (89%)	Forest (43%)

DISCUSSION

Overview

In this study, I evaluated whether Vermont's rare, threatened, and endangered plant and animal habitats are encompassed by GAP Status 1–3 protected lands or remain unprotected across the broader landscape. My results decisively support the hypothesis that most rare, threatened, and endangered plant and animal species occur outside protected lands, underscoring an urgent need for expanded conservation action to protect Vermont's biodiversity. Although ~448,000 ha of land is protected across Vermont's 18 subwatersheds, the majority of RTE habitats do not align with these protected areas. Statewide, only about 29% of RTE plant habitats and 35% of RTE animal habitats occur within GAP Status 1–3 jurisdictions, leaving ~58,000 ha of sensitive habitats exposed to habitat loss, ecological degradation, development pressure, and other human-driven disturbances. The uneven distribution of protected RTE habitats across subwatersheds further underscores the importance of subwatershed-specific conservation planning to identify where protection gaps are largest and where conservation efforts will be most impactful (Multi-Resolution Land Characterization Consortium, 2024; Vermont Agency of Natural Resources, 2025; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Patterns in land-cover associations reveal that RTE species rely heavily on forested ecosystems, wetland complexes, and open-water environments. Approximately 41% of all Vermont's unprotected RTE plant habitats occur within forests, with an additional ~29% located near or within open water and ~15% within wetland systems. Given that nearly 69% of Vermont's landscape is forested, it is unsurprising that the majority of both protected (~54%)

and unprotected (~41%) RTE habitats fall within forested land cover (Tables 3 and 4). These trends highlight the critical role that Vermont's forests and aquatic-edged environments play in sustaining RTE species, while also emphasizing the vulnerability of these habitats when they fall outside protected boundaries. Based on the ratio of protected to unprotected RTE plant and animal habitats, along with their distribution across different land-cover types and GAP 1-3 protected areas, I have classified the highest-priority regions for additional conservation as Tier 1 subwatersheds. Tier 2 subwatersheds represent landscapes where moderate protection levels overlap with substantial remaining habitat, making them strong candidates for targeted expansion of protections and for bolstering ecological connectivity (Multi-Resolution Land Characterization Consortium, 2024; Vermont Agency of Natural Resources, 2025; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Tier 1- Subwatersheds of Highest Concern for RTE Plants

Within Vermont, I have classified the following four subwatersheds as Tier 1 areas of concern for RTE plants: Lake Champlain (Figure A1), Mettawee River (Figure B2), Otter Creek (Figure B1), and St. Francois River (Figure A3). These subwatersheds contain Vermont's top four largest areas of unprotected RTE plant habitat, each hosting between 2,119 ha and 3,575 ha. With the addition of mass conservation efforts and subwatershed-wide prioritization of GAP 1-3 land implementation, these four subwatersheds have the potential to reduce the 20,325 total unprotected ha of RTE plant habitats by 51%. In the Lake Champlain, forests (31%) and open water (29%) are the subwatershed's dominant land cover in unprotected RTE plant habitats. Mettawee River hosts 55% of its unprotected RTE plant habitats in or around open water, with 28% found in forests. Otter Creek holds relatively even distributions of unprotected plants

between wetlands (43%) and forests (41%). Last, St. Francois River holds the majority (74%) of all unprotected RTE plants in and around open water environments. Between the four Tier 1 subwatersheds, there is a fairly even distribution of needed protections between open water, forested areas, and wetlands (Table 3) (Multi-Resolution Land Characterization Consortium, 2024; Vermont Agency of Natural Resources, 2025; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Tier 2 - Subwatersheds of Moderate Concern for RTE Plants

The following subwatersheds are categorized as Tier 2: Ammonoosuc River-Connecticut River (Figure A5), Hudson-Hoosic River (Figure B3), Black River-Connecticut River (Figure B4), and Winooski River (Figure A2). These subwatersheds hold Vermont's fifth through eighth largest concentrations of unprotected RTE plant habitat, each containing between 1,114 ha and 1,455 ha. Collectively, these four subwatersheds, with immense conservation efforts and additional land protections, could protect an additional 5,254 ha of RTE plant habitats. Within all four of the Tier 2 subwatersheds, the vast majority of unprotected RTE plant habitats are located within forests: Ammonoosuc River-Connecticut River (83%), Hudson-Hoosic River (62%), Black River-Connecticut River (52%), and Winooski River (42%). While there are other land cover areas, including open water and wetlands, that would benefit from additional GAP 1-3 protections, forest area protections would make the largest contribution to reducing the overall unprotected habitat area (Table 3) (Multi-Resolution Land Characterization Consortium, 2024; Vermont Agency of Natural Resources, 2025; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Tier 1 - Subwatersheds of Highest Concern for RTE Animals

In the same scope as RTE plants, I divided Vermont's subwatersheds into both Tier 1 and Tier 2 categories for unprotected RTE animals to identify priority areas for conservation and land protection. The Tier 1 RTE animal subwatersheds are as follows: Lake Champlain, Mettawee River, Otter Creek, and Winooski River. These four subwatersheds contain 25,897 ha of unprotected animal habitat, with each containing between 2,628 ha and 12,583 ha. In Lake Champlain, 47% of unprotected animal habitats fall in or around open water areas, Mettawee River (52%) and Winooski River (43%) subwatersheds show high concentrations of unprotected habitat in forested areas. Otter Creek, on the other hand, contains 43% of its unprotected habitats within agricultural lands (Table 4) (Multi-Resolution Land Characterization Consortium, 2024; Vermont Agency of Natural Resources, 2025; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Tier 2 - Subwatersheds of Moderate Concern for RTE Animals

For Tier 2 RTE animal habitats, most unprotected habitat hectares are concentrated within the West River-Connecticut River (Figure B5), St. Francois River (Figure A3), Lamoille River (Figure A4), and Black River-Connecticut River (Figure B4) subwatersheds. These subwatersheds contain an additional 5,815 ha of unprotected animal habitats and range from 1,275 ha to 1,869 ha. Both the West River-Connecticut River (52%) and Black River-Connecticut River (56%) hold most of their animal habitats within forests. Lamoille River is split evenly between open water (31%) and forests (32%). St. Francois River, on the other hand, primarily contains its unprotected animals in and around open water ecosystems (64%). This

majority distribution between two land cover types suggests that open water and forested ecosystems are the main targets for Tier 2 RTE animal habitat protection (Table 4) (Multi-Resolution Land Characterization Consortium, 2024; Vermont Agency of Natural Resources, 2025; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026).

Concluding Thoughts

My subwatershed-level analysis reveals a clear and consequential pattern: although Vermont maintains a substantial network of protected lands, these protections do not adequately overlap with areas most critical for sustaining rare, threatened, and endangered (RTE) plant and animal species. Only 29% of RTE plant habitats and 35% of RTE animal habitats fall within GAP 1-3 protected areas, leaving more than 57,000 ha of vulnerable habitat exposed to land-use change, development pressure, and ecological degradation (Multi-Resolution Land Characterization Consortium, 2024; Vermont Agency of Natural Resources, 2025; Vermont Fish & Wildlife Department, 2025; VT Center for Geographic Information, 2026). The spatial mismatch between protection and ecological need underscores the importance of targeted, habitat-driven conservation strategies that focus not only on expanding protected areas, but on doing so where biodiversity value is highest.

The subwatershed-specific findings provide clear direction for future conservation planning. Tier 1 subwatersheds, such as Lake Champlain, Mettawee River, Otter Creek, and St. Francois River for plants, and Lake Champlain, Mettawee River, Otter Creek, and Winooski River for animals, contain the largest shares of unprotected RTE habitats and represent the most urgent priorities for additional land-protection efforts (Vermont Agency of Natural Resources,

2025; Vermont Fish & Wildlife Department, 2025). These subwatersheds contain a variety of land cover types ranging from forests and wetlands to agricultural and open-water systems, demonstrating that no single conservation approach will meet the needs of all species or landscapes (Multi-Resolution Land Characterization Consortium, 2024). Instead, future efforts should integrate a combination of forest preservation, shoreline protection, wetland restoration, and private-land conservation incentives to ensure broad ecological resilience.

Overall, my study reinforces that protecting Vermont's biodiversity requires a more strategic alignment between conservation designations and the actual locations of sensitive species habitats. By using subwatershed-scale data to identify localized gaps in protection, land managers and policymakers can better prioritize limited resources, strengthen ecological connectivity, and support long-term habitat persistence amidst changing climate and land-use pressures. Continued investment in data-driven, spatially explicit conservation planning will be essential to securing Vermont's ecological integrity and ensuring that future generations inherit a biologically rich and resilient landscape.

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APPENDICES

APPENDIX A

SUBWATERSHEDS OF NORTHERN VERMONT

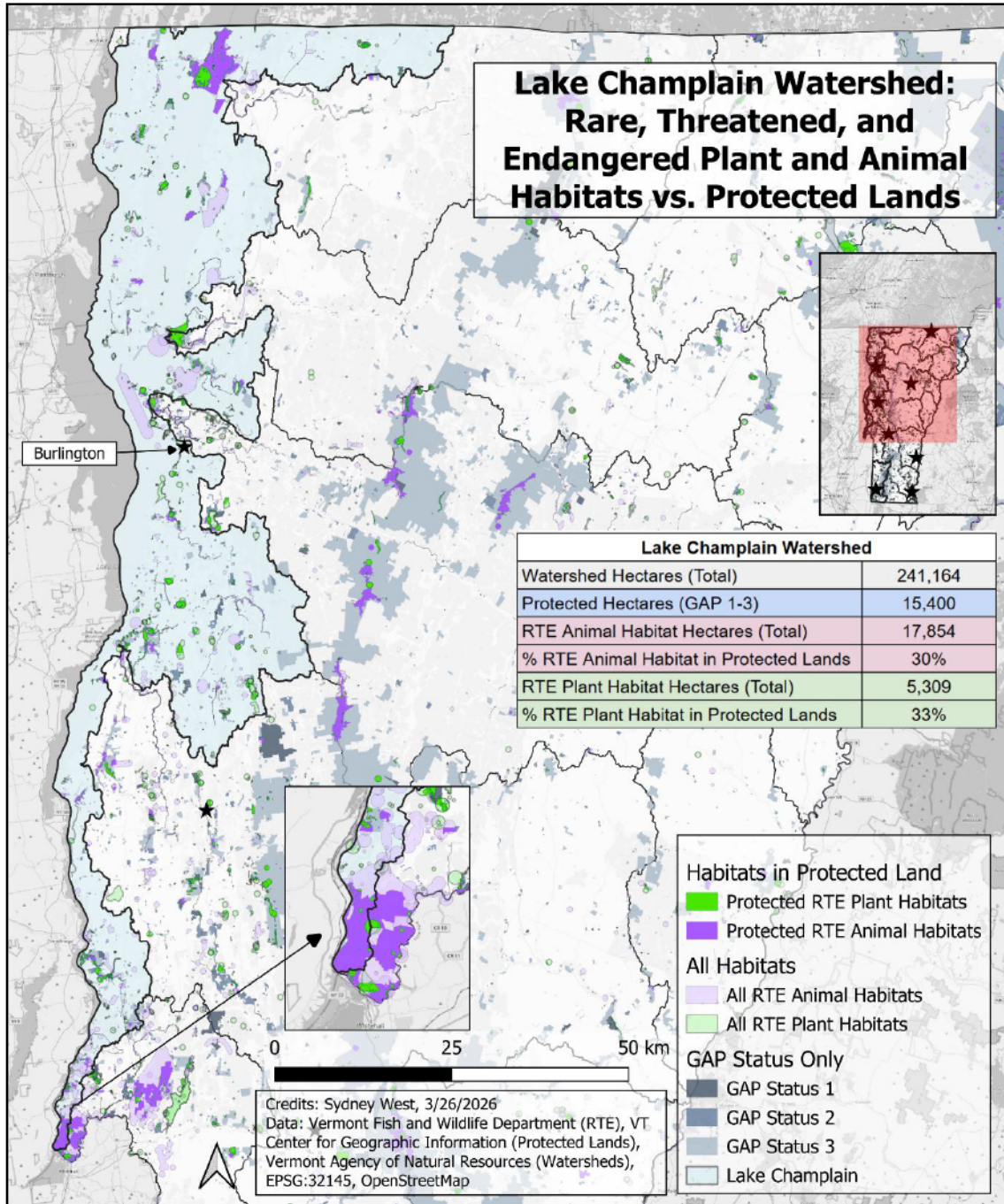


Figure A1. Lake Champlain subwatershed and its GAP 1-3 lands and RTE plants and animals.

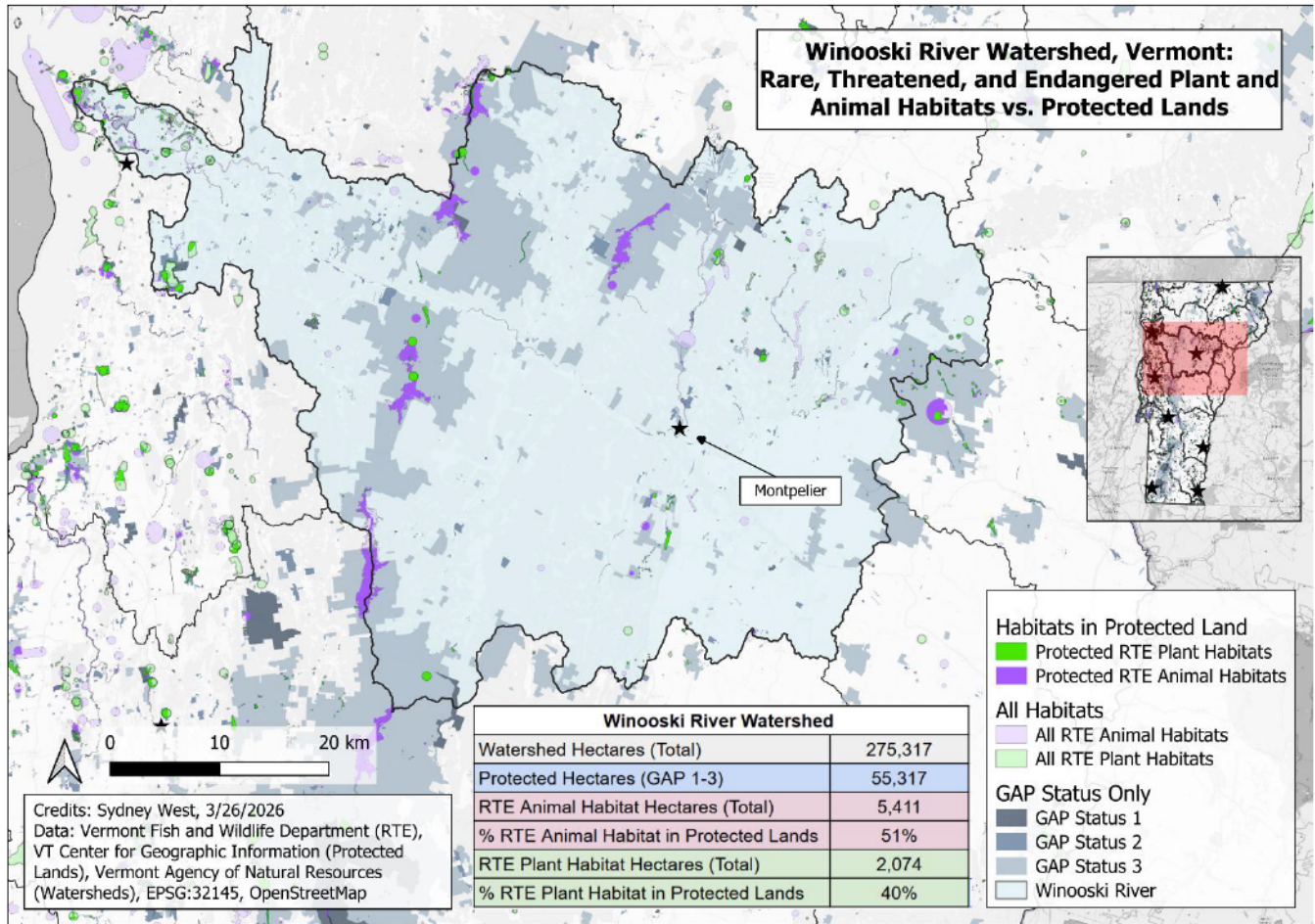


Figure A2. Winooski River subwatershed and its GAP 1-3 lands and RTE plants and animals.

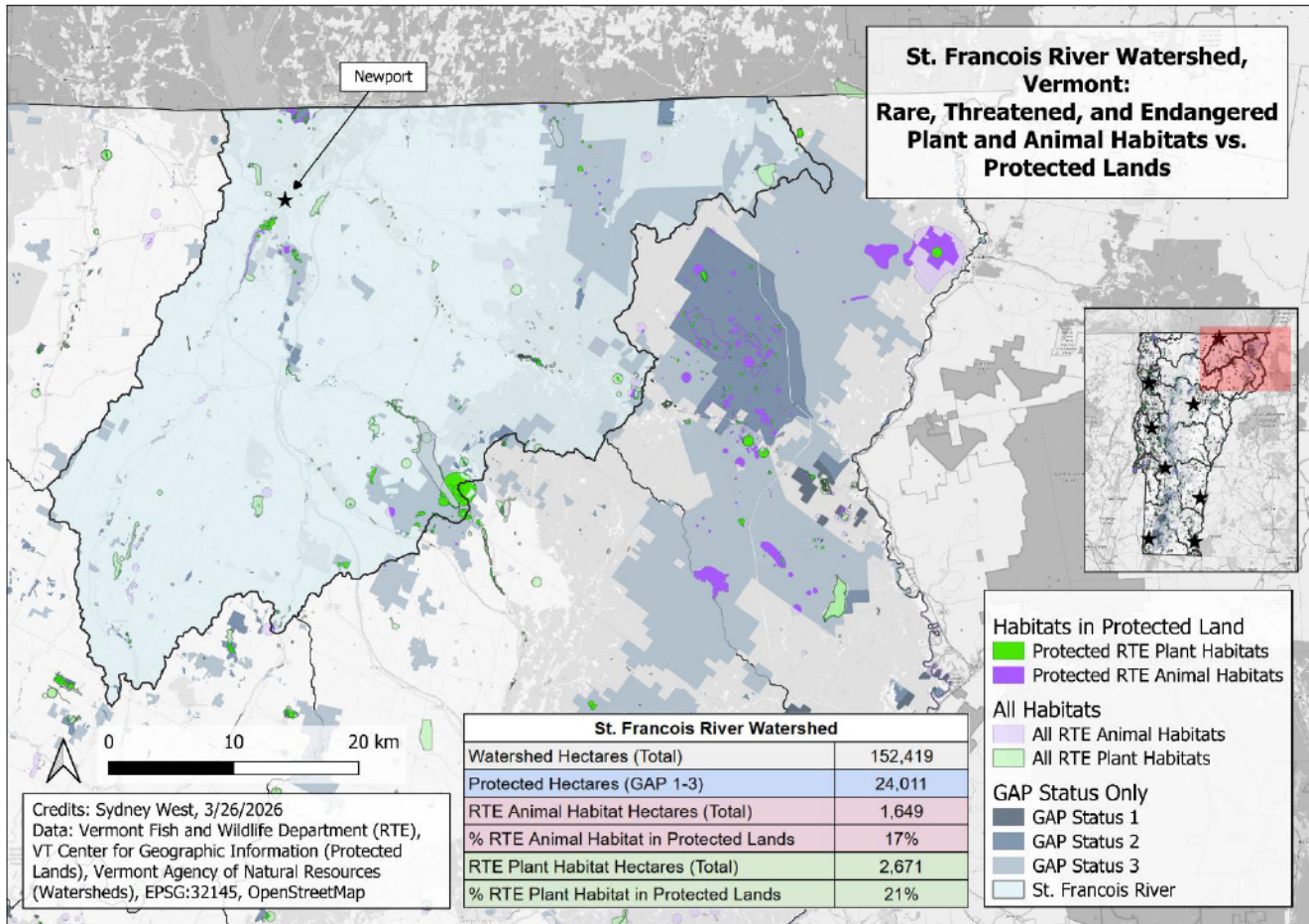


Figure A3. St. Francois River subwatershed and its GAP 1-3 lands and RTE plants and animals.

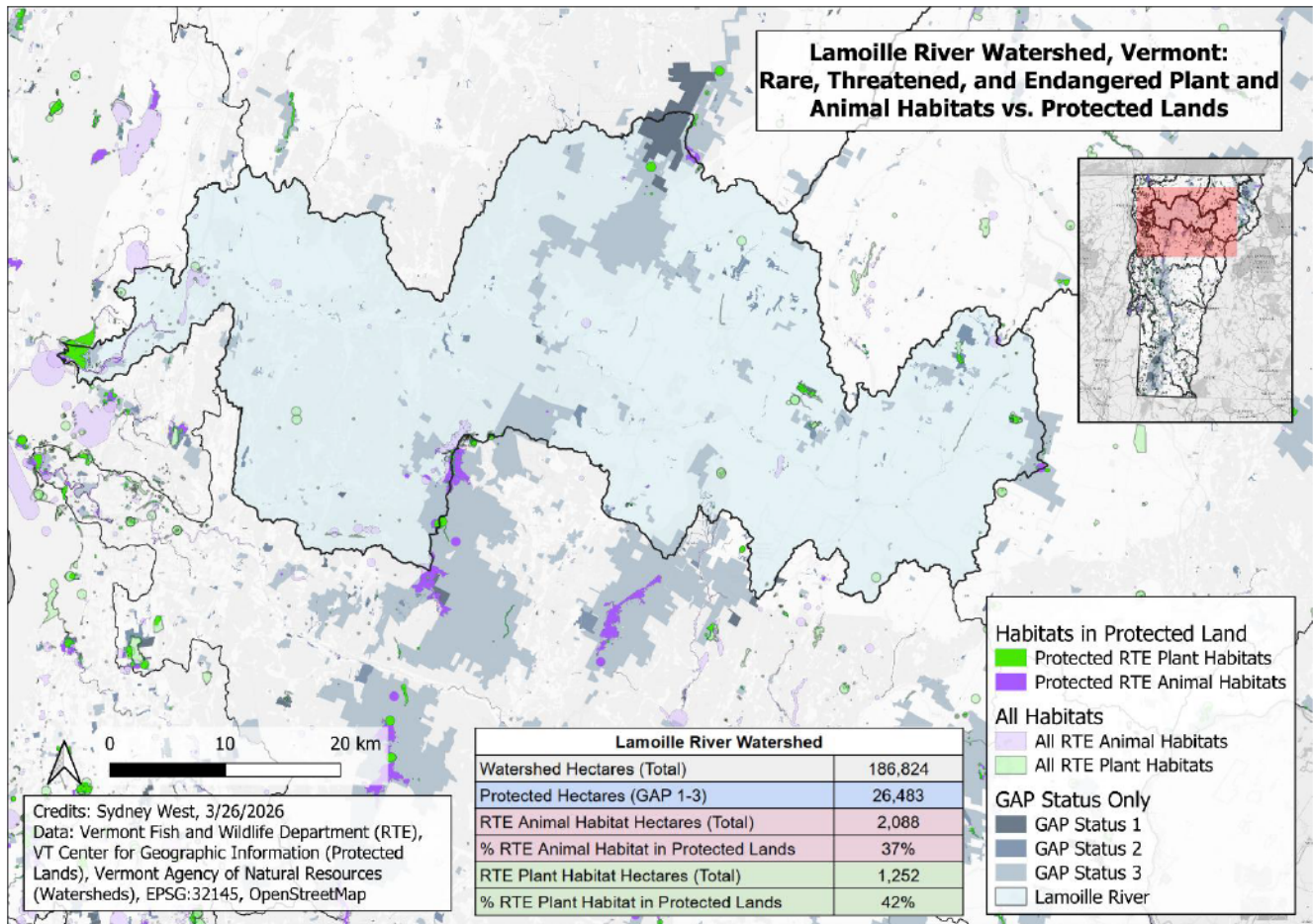


Figure A4. Lamoille River subwatershed and its GAP 1-3 lands and RTE plants and animals

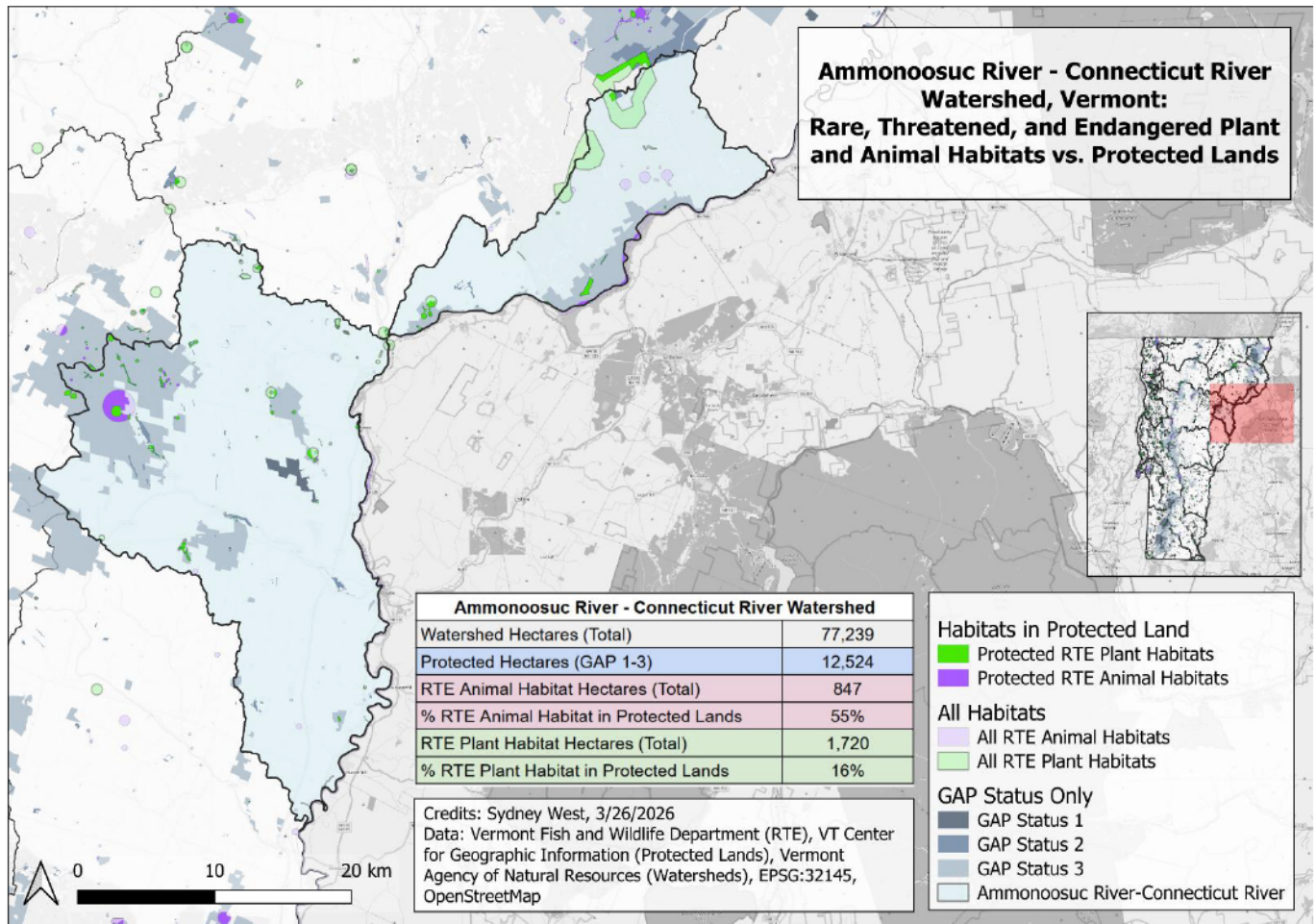


Figure A5. Ammonoosuc River – Connecticut River subwatershed and its GAP 1-3 lands and RTE plants and animals.

APPENDIX B

SUBWATERSHEDS OF SOUTHERN VERMONT

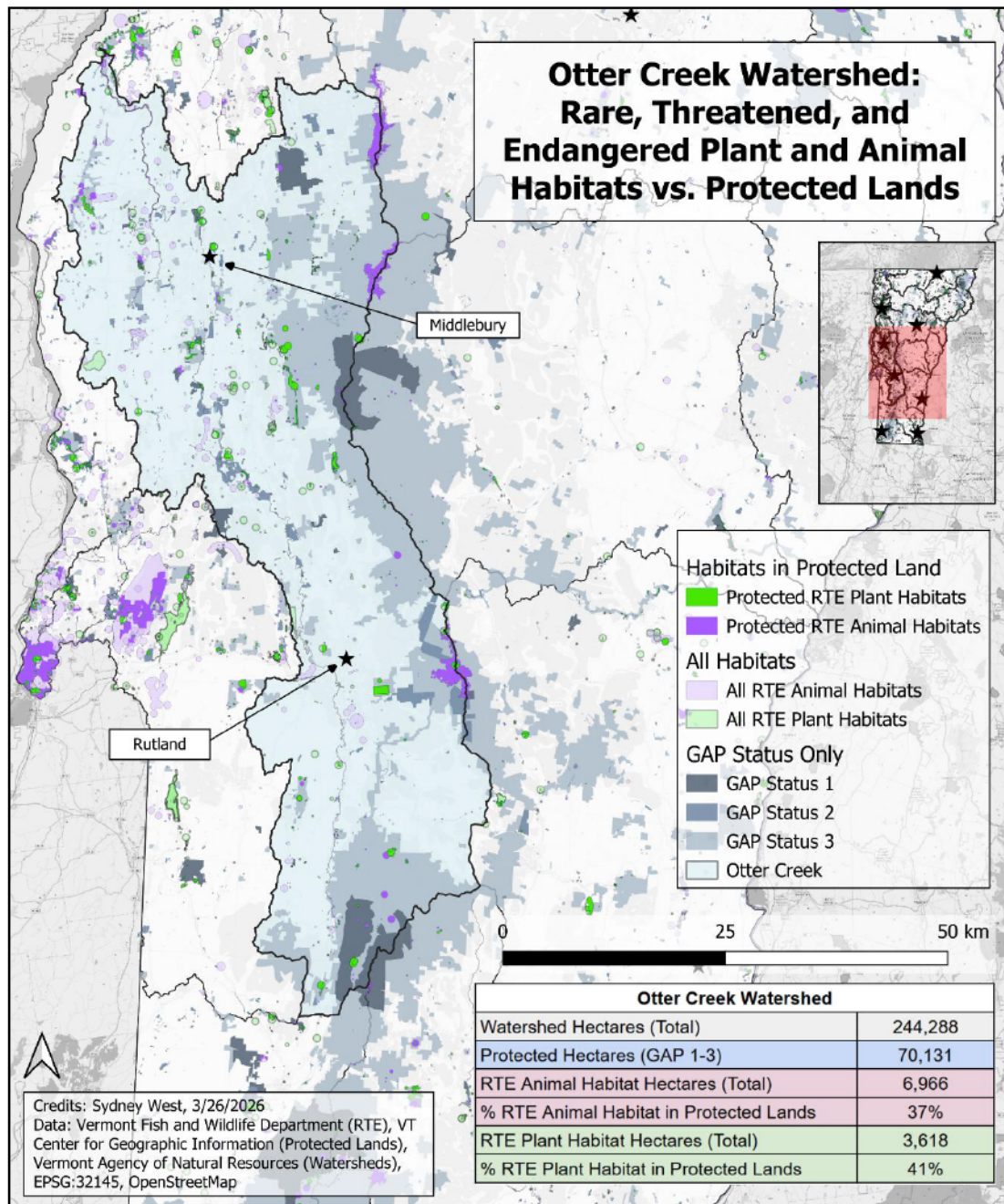


Figure B1. Otter Creek subwatershed and its GAP 1-3 lands and RTE plants and animals.

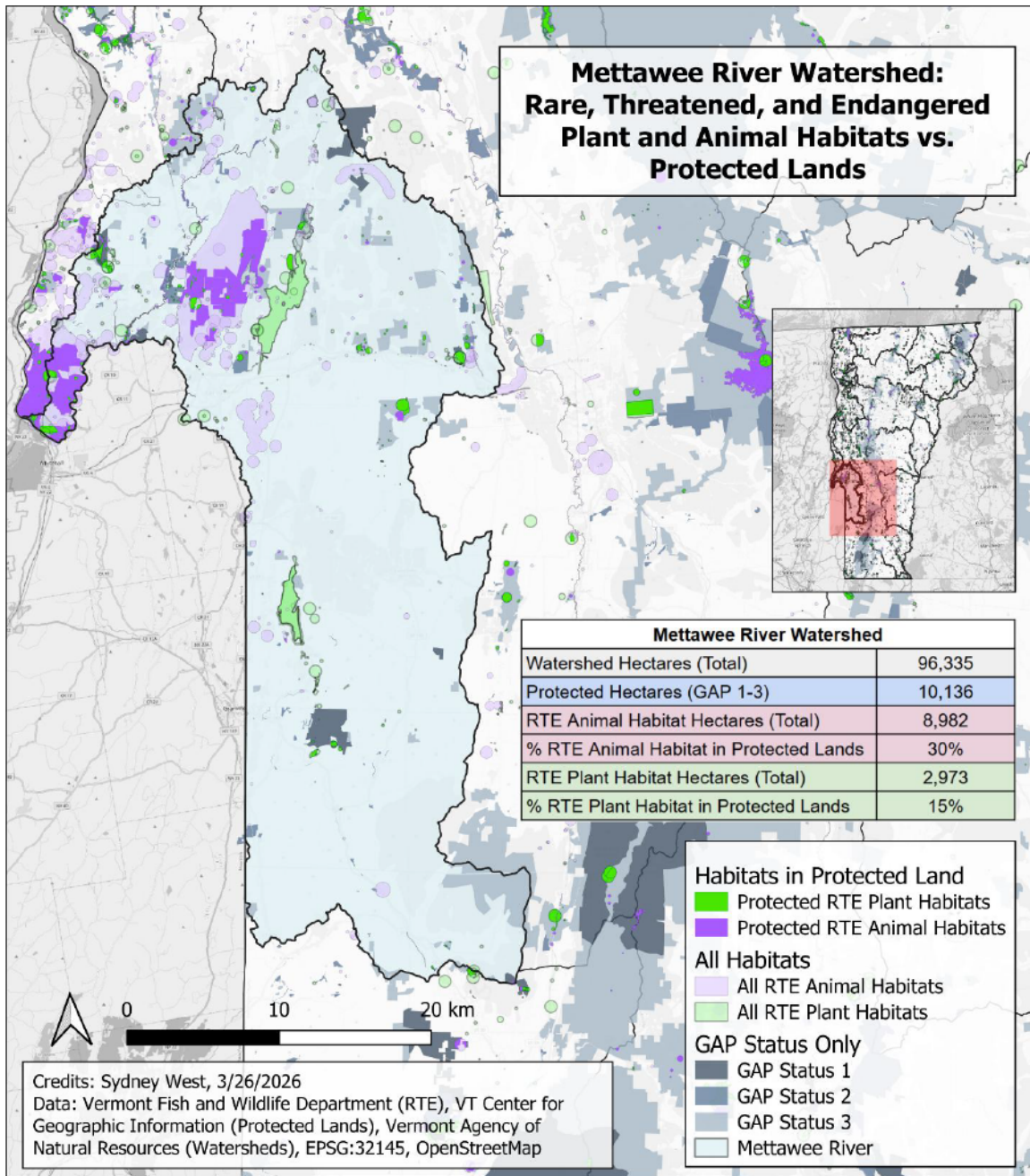


Figure B2. Mettawee River subwatershed and its GAP 1-3 lands and RTE plants and animals.

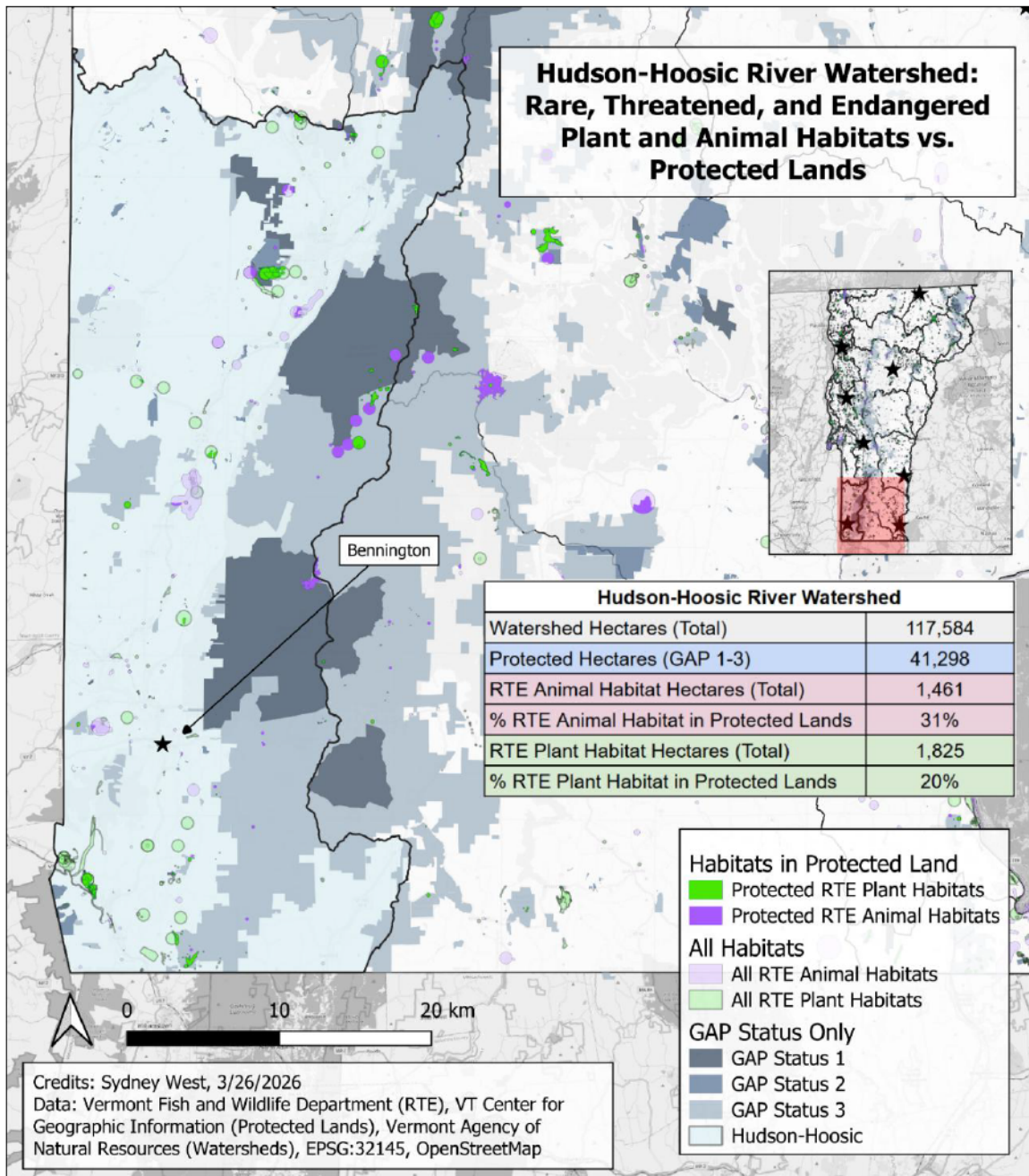


Figure B3. Hudson – Hoosic subwatershed and its GAP 1-3 lands and RTE plants and animals.

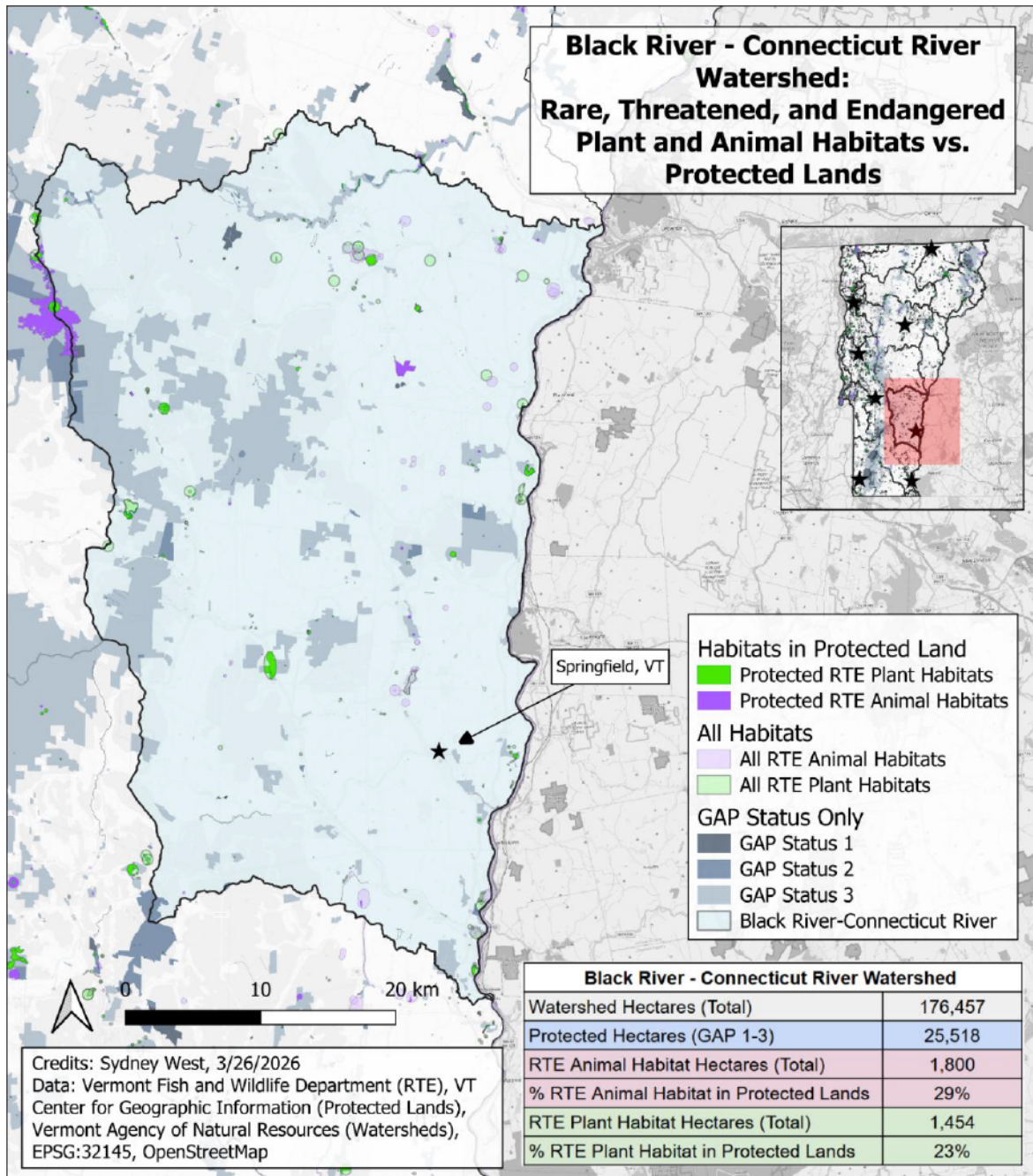


Figure B4. Black River subwatershed and its GAP 1-3 lands and RTE plants and animals.

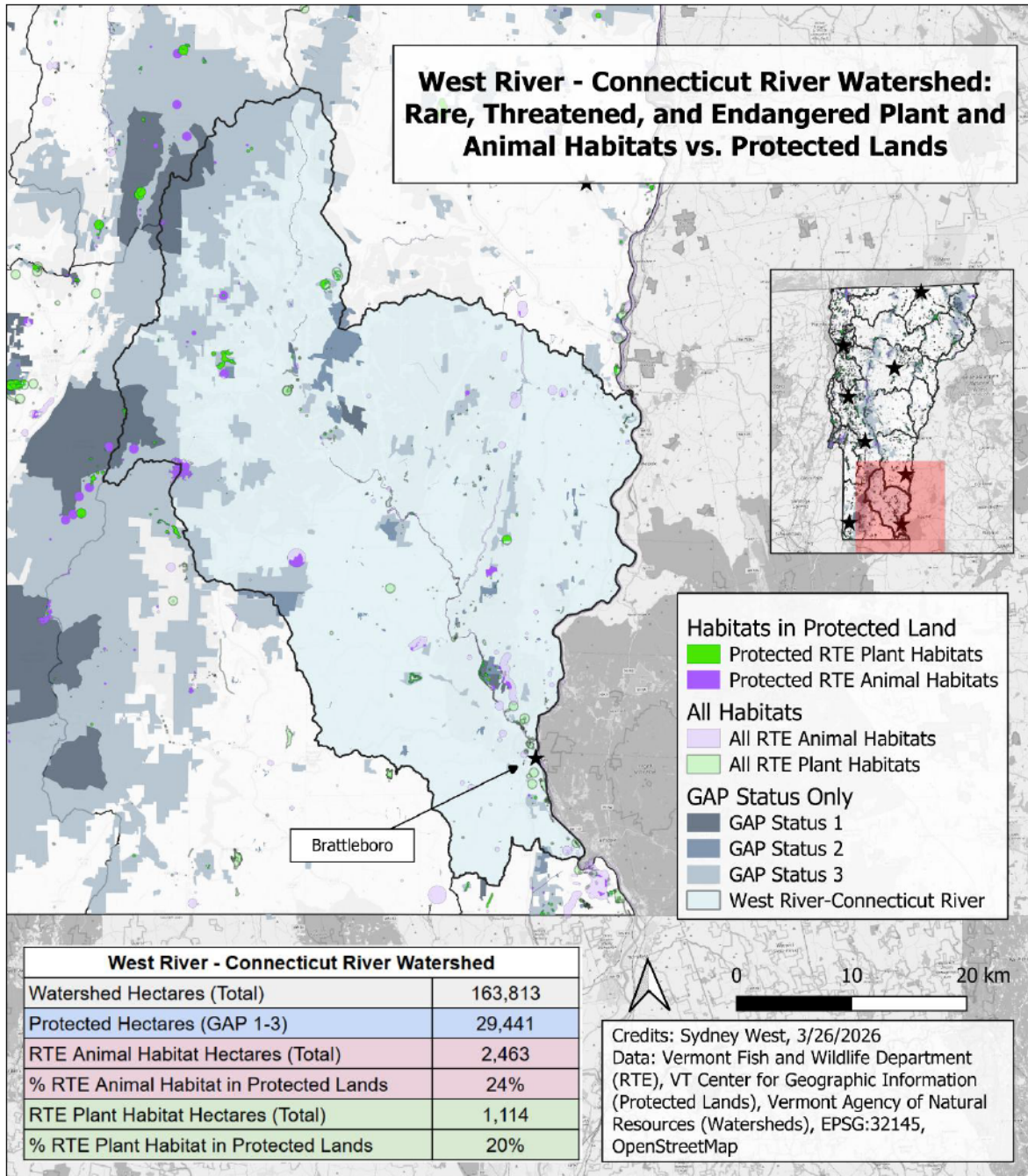


Figure B5. West River - Connecticut River subwatershed and its GAP 1-3 lands and RTE plants and animals.