WILDLIFE & SUGARING

Vermont's Sugaring Operations and Potential Implications for Wildlife

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Table of Contents

Executive Summary

Vermont's maple sugaring industry has grown substantially in recent decades, raising questions about how larger-scale sugaring operations influence wildlife habitat and movement. However, few studies have examined how commercial maple sugaring impacts wildlife (Isselhardt and Perkins 2018). With the recent rise in Vermont's maple syrup production and a gap in knowledge about how sugaring operations impact wildlife habitat and movement, a multi-scale assessment was conducted, including an overview of Vermont's natural history and evolution of sugaring over the years, a landscape-scale geospatial assessment exploring the overlap of sites that actively sugar and the state's high value ecological areas, and a site-level field assessment measuring sugaring infrastructure, wildlife occurrences, and their habitat within sugarbushes across Vermont. This report highlights findings from these assessments, recommends management practices that support wildlife habitat, and suggests avenues for future research.

Vermont's sugarbushes are commonly associated with Northern Hardwood Forests, a widespread and ecologically important system shaped by climate, topography, and glacial history (Matthews and Iverson 2017; Thompson et al. 2019). These forests support a high diversity of wildlife, including species that rely on a range of habitat conditions and structural features such as coarse woody debris, standing dead trees, pools of water, and forest openings (DeGraaf et al. 2006; Kenefic and Nyland 2000). Historically, sugarbush management emphasized maximizing sap production by promoting sugar maple dominance, often simplifying forest structure. During the 19th and early 20th centuries, when much of Vermont's landscape was deforested for agriculture, sugaring often occurred within isolated stands of maple trees managed primarily for sap production, with these woodlots functioning more as orchards than forests. As Vermont's forests regenerated, sugaring became embedded within larger contiguous forest systems, where forest management decisions increasingly influence not only sap production, but also wildlife habitat and landscape connectivity. Today, many sugarmakers adopt biodiversity-focused management practices (Pratson et al. 2026), with programs such as Vermont's Use Value Appraisal further encouraging integrated management approaches that maintain forest cover and ecological function while also supporting working forests such as sugarbushes.

A landscape-level assessment evaluated the overlap between forests of parcels that actively sugar, as identified through the Use Value Appraisal, and areas of high ecological value and wildlife movement. This was conducted using twelve key ecologically important components mapped by the Vermont Conservation Design components, and statewide Species Movement models for six of Vermont's larger mammals provided by Drasher et al. (2025). Forest characteristics, including vegetation type, as well as soils, geology, and topography, were also summarized to better understand available wildlife habitat within these forests that sugarmakers manage. Results showed that although sugaring occurs across 7.7% of Vermont's forestland, these forests disproportionately overlapped with high value habitat blocks, interior forests, and connectivity corridors (**Figure 7**; **Figure A1**), with over 80% of all forest managed by sugarmakers supporting high value movement opportunities for species such as bobcat (*Lynx rufus*), coyote (*Canis latrans*), American black bear (*Ursus americanus*), moose (*Alces alces*), and white-tailed deer (*Odocoileus virginianus*; **Figure 9**; **Figure A3**; **Table A3**). Species-level features such as vernal pools were relatively rare, but a greater proportion of all mapped high-value vernal pool area occurred within sugared forests than for any other component examined (**Figure A2**). These findings illustrate that sugaring occurs within naturally sugar maple-dominated forests and across ecologically valuable areas of interior forest habitat and wildlife connectivity.

A site-level assessment evaluated wildlife habitat, sugaring infrastructure, and wildlife occurrence within actively managed sugarbushes across Vermont. This was conducted by surveying paired core and edge plots at twenty sites, where vegetation structure, special habitat features, taps and tubing, and wildlife detections from trail cameras and audio devices were measured. Results showed that sugarbushes were predominantly mid-successional, sugar maple-dominated forests (**Figure 17**) characterized by moderate species and structural diversity with relatively few large trees. Coarse woody debris and standing dead trees were limited and generally small in size, while early-successional and mature forest conditions were scarce. Wildlife detections showed minimal relationship between core and edge, with only hermit thrush detected significantly more at the core and black-throated blue warbler detected significantly more at the edge (**Table 8**). Although not significant, white-tailed deer and American black bear were commonly detected along sugarbush edge, while North American porcupine and flying squirrels were more frequently detected in the sugarbush core (**Table 7**). Tap density and tubing did not differ between core and edge plots and showed inconsistent relationships with wildlife species, with some species decreasing and others increasing in response to increased taps or tubes. Camera trap observations also did not provide clear evidence that tubing impeded wildlife movement, with the possible exception of moose.

From this work, opportunities emerge to maximize wildlife habitat within sugarbushes, including management that leaves large coarse woody debris, large slash piles, and large standing dead trees, while maintaining a diversity of tree species and size classes. Wet areas such as vernal pools are also important for a wide range of wildlife species. Together, these findings suggest that modern sugaring can support both maple production and wildlife habitat, given management that maintains forest structural diversity and habitat features. Future research should focus on species-specific responses to sugaring infrastructure, particularly whether tubing influences the movement of moose. A more targeted study design with larger sample sizes and clear categorical differences between site conditions would help clarify relationships between wildlife, habitat, and sugaring infrastructure within sugarbushes.

Introduction

Vermont is the leading maple producer in the United States, producing over 11 million liters (3 million gallons) of syrup in 2025 – compared to 3 million liters (829,000 gallons) in New York, the second-largest U.S. producer (USDA National Agricultural Statistics Service 2025). Although Vermont reached similar production levels during the early 20th century (Vermont Historical Society 2021), maple syrup production has increased more than sixfold since 2000, rising from 1.8 million liters (480 thousand gallons) to 11.6 million liters (3 million gallons) between 2000 and 2025 (USDA National Agricultural Statistics Service 2025; **Figure 1**). This growth not only reflects the continued economic and cultural importance of sugaring in the state, but also a potential shift in operation scale and intensity.

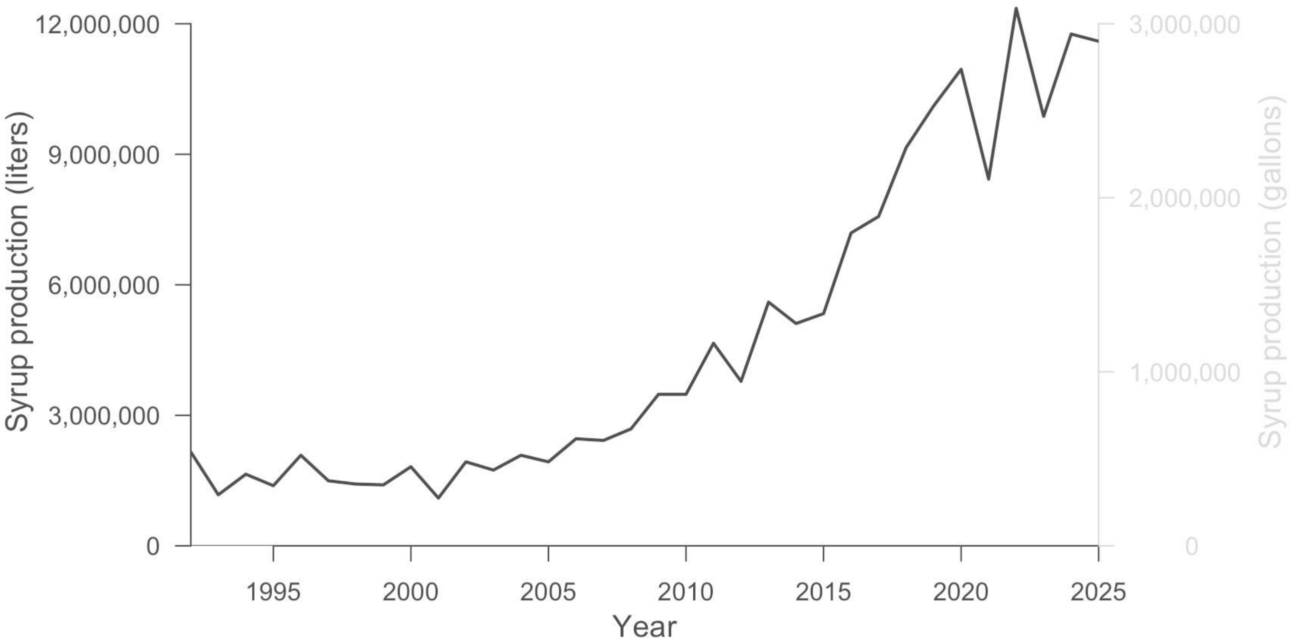

Figure 1. Syrup production in Vermont from the USDA National Agricultural Statistics Service.

While studies on maple sugaring impacts have historically focused on tree health, notably by researchers at the Cornell Uihlein Maple Forest and the UVM Proctor Maple Research Center (PMRC), there is little information on how sugaring infrastructure and sugarbush management affect wildlife habitat quality and connectivity across Vermont's forests. In 2018, answering a bipartisan request from the Vermont House Committee on Natural Resources, Fish and Wildlife about the impact of the maple industry on forestlands, PMRC's response regarding wildlife mentioned that "although concerns have been raised about how maple tubing systems might affect wildlife, there is no clear understanding in the literature on the subject."

Project Background

To address this gap in knowledge, the UVM Field Naturalist Program has partnered with the Forest Legacy Program within the Vermont Department of Forests, Parks & Recreation (FPR), with support from the Vermont Fish and Wildlife Department (VT F&W), to better understand the relationship between sugaring and wildlife. This project examines how bird and large mammal occurrence may change with sugaring intensity. It should be noted that while the word ‘intensity’ may have a negative connotation, some wildlife species may respond positively to forest disturbance or silvicultural changes within Northern Hardwood Forests (Litvaitis 2003; Stoleson 2019). Neutral outcomes, where wildlife species are not clearly impacted by forest management, are also possible (Brawn et al. 2001; Fulbright 2023; Morse 2025). The intention of the following report is to highlight ways that the positive impacts of the maple sugaring industry can be supported, and the negative impacts minimized, ultimately guiding future research and management decisions that promote ecological integrity across Vermont’s forests, including maple production stands.

Chapter 1: The Story of Sugaring and Wildlife in Vermont

Natural History of Sugarbushes in Vermont

Northern Hardwood Forests

Sugar maple (Acer saccharum), one of the dominant late-successional species of Northern Hardwood Forests, thrives where nutrients from minerals and leaf litter accumulate along Vermont's hillsides (Leak 1982). This tree species is most abundant on cool, moderately well-drained soils that are relatively rich in calcium and magnesium. These minerals – especially calcium, which supports the sugar maple's nutrient transport system (Juice et al. 2006; Long et al. 2009) that many of us have come to appreciate during spring sap flow – derive from an ancient seafloor deposited over Vermont approximately 541-393 million years ago (Ratcliffe et al. 2011). Subsequent uplifting from collisional mountain-building events 480-300 million years ago formed the Taconic and Green Mountains that characterize Vermont's sloping terrain. These mountains were further transformed during the continual advancement and retreat of the Quaternary glaciers (2.58 million-10,000 years ago; Rayburn et al. 2011) as ice sheets up to 2 km (1 mile) ground and redistributed bedrock across the region. Behind the ice sheet's final retreat, these glacial soils formed a foundation for future plant communities. Tundra first occupied the newly exposed earth, followed by coniferous, and eventually deciduous forests as the climate warmed, with sugar maple expanding northward from multiple southern refugia (Whitehead 1979; Vargas-Rodriguez et al. 2015). By this time, much of the region was covered in near-continuous tree canopy (Cogbill 2000) and long inhabited by Algonquian-speaking peoples and the Haudenosaunee, both of whom practiced maple sugaring (Pendergast 1982). Following European colonization of the 1600s and over 400 years of more intensive land use, Vermont has gone from 35% forested by 1900 to 77% forested today, with increases in maple abundance driven largely by the regrowth of forests across abandoned hillside farms (Bürgi et al. 2000). From this context, and under ever-changing conditions, the now vast Northern Hardwood Forest serves as a backdrop as we consider sugaring in relation to wildlife in Vermont.

Wildlife

Northern Hardwood Forest is widespread and supports a wide range of wildlife in Vermont and New England. Summarizing *The Technical Guide to Forest Wildlife Habitat Management in New England* (DeGraaf et al. 2006), 63 (17 + 46) mammal species rely on (prefer + utilize) Northern Hardwood Forests for their habitat requirements, alongside 131 (40 + 91) birds, 13 (1 + 12) reptiles, and 11 (0 + 11) amphibians. These habitat requirements are important to consider when managing forests for extractive uses, including maple sap production.

Figure 2. Moose moving beneath tubes in a sugarbush in Marshfield, Vermont.

Rare Species that Use or Prefer Northern Hardwood Forests

Four of Vermont's rare wildlife species prefer Northern Hardwood Forests; Canada lynx (*Lynx canadensis*; state endangered; federally threatened; S1 very rare), Tennessee warbler (*Leiothlypis peregrina*; S1), eastern whip-poor-will (*Antrostomus vociferus*; state threatened; S2 rare), and northern goshawk (*Accipiter gentilis*; S2; Vermont Natural Heritage Inventory 2025a and 2025b). The required habitat types for each species are detailed in **Table 1** and **Table 2** below. There are also a number of rare species that use, rather than specifically prefer, Northern Hardwood Forests and the associated microhabitats within them (**Table 1**; **Table 2**; **Table 3**). Of note, all of these species require a broad range of habitat types within the broader Northern Hardwood Forests, with habitat requirements including woodland openings, early successional-to-open forests, mature forests, and hardwood swamps, as well as site-level requirements like large standing dead cavity trees and a forest floor with abundant rocks or coarse woody debris (DeGraaf et al. 2006). The Northern Hardwood Forests, and the sugarbushes therein, encompass these natural community features and have the potential to support the wide range of habitat conditions required by these species when managed accordingly.

Table 1. Rare mammals within Northern Hardwood Forests with state and federal rankings (Vermont Natural Heritage Inventory 2025a) and habitat considerations as described by DeGraaf et al. (2006).

Common name	Scientific name	Rank	Habitat considerations
American marten	*Martes americana*	SE, S1	Hollow trees, coarse woody debris
Gray wolf	*Canis lupus*	FE, SE, SX	Seclusion, abundant prey (deer)
Canada lynx	*Lynx canadensis*	FT, SE, S1	Seclusion, dense understory cover, abundant prey (snowshoe hare)
Mountain lion	*Puma concolor*	SE, SH	Seclusion; abundant prey (deer)
Silver-haired bat	*Lasionycteris noctivagans*	S2	Tree cavities and loose bark for roosting
Little brown bat	*Myotis lucifugus*	SE, S1	Woodlands with openings for hunting
Northern long-eared bat	*Myotis septentrionalis*	FE, SE, S1	Tree cavities and loose bark for roosting
Indiana bat	*Myotis sodalis*	FE, SE, S1	Tree cavities and loose bark for roosting
Tri-colored bat	*Perimyotis subflavus*	SE, S1	Woodlands with openings for hunting
Long-tailed or rock shrew	*Sorex dispar*	SC, S2	Rocky woodlands
Eastern pygmy shrew	*Sorex hoyi*	S2	Moist leaf litter near water
New England cottontail	*Sylvilagus transitionalis*	SC, SH	Dense understory cover
Rock vole	*Microtus chrotorrhinus*	SC, S2	Rocky woodlands
Southern bog lemming	*Synaptomys cooperi*	S2	Moist soils, grass-sedge ground cover

FE = Federally endangered; FT = Federally threatened; SE = State endangered; SC = State species of concern; S1 = Very rare; S2 = Rare; SH = State historic; SX = State extirpated

Table 2. Rare birds within Vermont's Northern Hardwood Forests with state rankings (Vermont Natural Heritage Inventory 2025b) and habitat considerations as described by DeGraaf et al. (2006).

Common name	Scientific name	Rank	Habitat considerations
Northern goshawk	*Accipiter gentilis*	S2	Mature mixed woodlands
Eastern whip-poor-will	*Antrostomus vociferus*	ST, S2	Woodlands by openings, old field edges, abandoned orchards
Long-eared owl	*Asio otis*	S1	Dense conifers by open land, wetlands
Red-shouldered hawk	*Buteo lineatus*	S2	Cool, moist mature forest
Bald eagle	*Haliaeetus leucocephalus*	S1	Large nest trees by water containing fish
Tennessee warbler	*Leiothlypis peregrina*	S1	Early successional-to-open coniferous-deciduous forest
Philadelphia vireo	*Vireo philadelphicus*	S1	Hardwood forest edges, early successional forests

ST = State threatened; S1 = Very rare; S2 = Rare

Table 3. Rare amphibians and reptiles within Vermont's Northern Hardwood Forests with state rankings (Vermont Natural Heritage Inventory 2025c) and habitat considerations as described by DeGraaf et al. (2006).

Common name	Scientific name	Rank	Habitat considerations
Fowler's toad	*Anaxyrus fowleri*	SE, S1	Sandy soils, shallow water for breeding
Spotted turtle	*Clemmys guttata*	SE, S1	Wetlands, vernal pools, dry openings for nesting
North American racer	*Coluber constrictor*	ST, S1	Open areas, wetlands
Eastern ribbonsnake	*Thamnophis saurita*	SC, S2	Shallow water in open, grassy habitat

SE = State endangered; SC = State species of concern; S1 = Very rare; S2 = Rare

Common Species Associated with Northern Hardwood Forests

Many common wildlife species prefer Northern Hardwood Forests and no other forest type. Although they might utilize other forest types, their singular preference for Northern Hardwood Forests highlights the importance of these forests for such species. These include red-eyed vireo (*Vireo olivaceus*), black-throated blue warbler (*Setophaga caerulescens*), willow flycatcher (*Empidonax traillii*), smokey shrew (*Sorex fumeus*), and fisher (*Pekania pennanti*). Others require Northern Hardwood Forests and only one other forest type, including veery (*Catharus fuscescens*) and American redstart (*Setophaga ruticilla*), which also prefer swamp hardwood forests, wood thrush (*Hylocichla mustelina*), black-and-white warbler (*Mniotilta varia*), and scarlet tanager (*Piranga olivacea*), which also prefer oak-pine forests, and black-throated green warbler (*Setophaga virens*), which also prefers hemlock forests.

Vermont's four rare amphibians and reptiles (**Table 3**) all require either vernal pools, shallow water, or more herbaceous wetlands for critical life stages. Vernal pools within Northern Hardwood Forests also provide critical breeding habitat for many of the more common amphibian species such as Vermont's three mole salamanders (*Ambystoma jeffersonianum*, *A. laterale*, and *A. maculatum*), wood frog (*Lithobates sylvaticus*), spring peeper (*Pseudacris crucifer*), American toad (*Anaxyrus americanus*), and eastern newt (*Notophthalmus viridescens*).

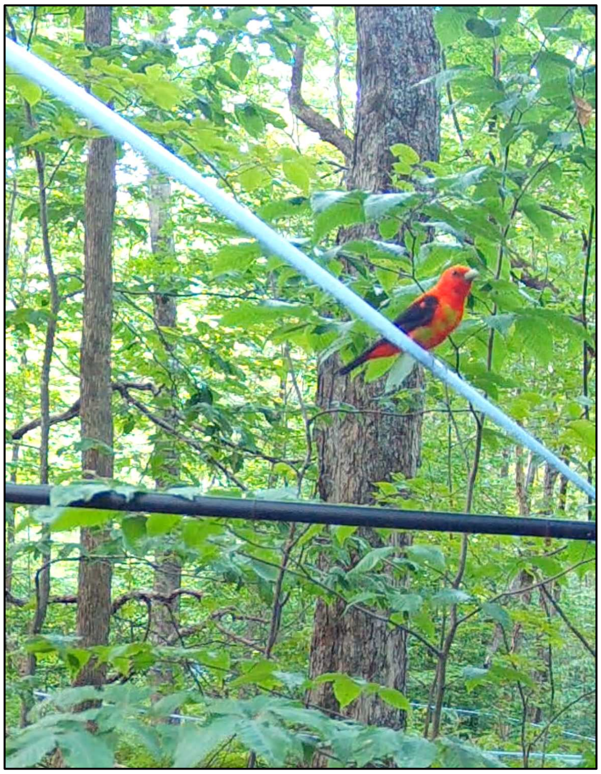

Figure 3. Scarlet tanager perches on a tube in Chittenden, Vermont.

Additional Wildlife Considerations

Larger mammal species like moose (*Alces alces*), white-tailed deer (*Odocoileus virginianus*), and American black bear (*Ursus americanus*) are common in these forests and their larger size and home range requirements suggest a need for additional research to determine if movement is limited by tubing in modern sugarbushes. More broadly, early spring sap collection coincides with a critical period of biological activity, when many species emerge from winter dormancy and migrate to find food or breeding grounds. During this time, increased human presence may elevate the risk of stress or mortality to these species (Naughton 2021). For species sensitive to disturbance or that require a greater degree of seclusion, these factors may reduce the suitability of sugarbushes as habitat despite otherwise suitable forest conditions.

Changing Face of Sugaring

Sugarbush management has historically been oriented toward maximizing sap production through promotion of large sugar maples, emphasizing wide spacing and crown expansion. To achieve this, early sugarbush silviculture guides recommended removing tree species that could compete with sugar maples (Cope 1946; Gabriel and Walters 1974), often resulting in near-monoculture composition. These approaches were influenced by labor constraints of bucket collection, which favored sugarbushes with fewer, larger trees (Isselhardt et al. 2022). During the 19th and early 20th centuries, when much of Vermont's landscape was cleared for agriculture, many sugarbushes existed as relatively isolated patches of maple trees, functioning more as orchards rather than forest stands. As forests regenerated over the past ~150 years, these sugarbushes increasingly became embedded within larger contiguous forest systems.

Today, with approximately 67% of Vermont's forestland held in non-industrial private ownership (USDA Forest Service 2025), individual landowners play a central role in shaping forests across the state. Therefore, forest management decisions are increasingly understood to influence ecological conditions at the landscape scale rather than only within individual parcels. As sugaring occurs across many of these privately owned forests, individual sugarbush decisions are increasingly recognized for their collective influence in shaping Vermont's forests as a broader, interconnected system.

Within this context of private forest economics, the Use Value Appraisal (UVA) program, first implemented in 1980, has become a key policy tool that supports landowners in keeping large areas of forest intact while also guiding management decisions, when enrolled as Forestland with Vermont Forests, Parks and Recreation (FPR). By maintaining forest cover and requiring long-term management plans for each landowner, UVA provides a framework for sugarbushes to be managed not only for sap production, but as part of a collection of working forests with multiple values, including wildlife habitat.

More recently, the Vermont Conservation Design (VCD) project led by Vermont Fish & Wildlife Department (VFWD) has highlighted areas across the state that are particularly important for maintaining Vermont's ecological integrity, allowing landowners to consider how their property fits within broader patterns of landscape- and habitat-level functionality. The growing utilization of programs like these, as well as the growing popularity of programs like Audubon's Bird-friendly Maple (Vermont Organic Farmers and Audubon Vermont 2025), reflect this transition from single-objective management toward a more integrated way of thinking in which sugaring and management for wildlife habitat can occur within the same forest with little to no additional cost to sugarmakers (Pratson et al. 2026).

Chapter 2: Geospatial Assessment of Sugarbushes

Introduction

Many sugarmakers with ≥10.1 ha (≥25 acres) of forestland enroll their parcel with UVA. While the Forestland category of UVA enrollment allows land to be taxed based on its value for producing forest products rather than its development value, it also requires additional stipulations, including that the forest be managed under a 10-year forest management plan prepared by a licensed forester and approved and inspected by FPR. For sugared forests enrolled as Forestland in Use Value Appraisal, forest management plans must follow Sugarbush Management Standards and Tapping Guidelines as well as Vermont's Acceptable Management Practices (AMPs). These standards provide guidance for retaining diversity of tree species and size classes and protecting sensitive features like wetlands, while also encouraging management practices that retain standing dead trees and coarse woody debris. They also ensure that forest roads and trails are established and maintained using practices that minimize erosion and soil compaction. Depending on enrollment category and recommendations developed by the licensed forester in consultation with the landowner, forest management plans may also include practices that support understory regeneration, reduce invasive species, or protect sensitive natural communities. Collectively, these practices can help maintain forest conditions associated with structural diversity, habitat connectivity, and resistance to pests, pathogens, and climate-related stressors (Thompson et al. 2009; Hilty et al. 2019). Thus, forest management plans under UVA not only support maple production economically, but can also help maintain long-term forest conditions that promote diversity of tree species and forest structure and, in turn, provide habitat for a wide range of wildlife species.

Figure 4. Bobcat family moving through a sugarbush in Starksboro, Vermont.

The statewide prioritization of Vermont's areas of critical ecological integrity as delineated by VCD has also been pivotal in understanding forest parcels in the context of the broader biological landscape. Through VCD, landscape- and habitat-level components have been categorized based on their importance for maintaining wildlife habitat and ecosystem functionality. For example, the Interior Forest component identifies the state's largest unfragmented forest blocks that are required for the more seclusive wildlife species that prefer habitat away from a forest's edge. Similarly, the Vernal Pool component identifies areas that support or likely support vernal pools that provide a nursery for many of Vermont's more sensitive wildlife species. When considered together, VCD allows for an assessment of which ecological functions are most important for any given area and can guide land management accordingly.

By examining where UVA parcels that indicate sugaring occur alongside VCD areas of highest ecological importance, we can better understand which ecological components are most associated with sugaring relative to Vermont's forests statewide. Two questions guided this assessment: 1) how much does each component overlap with forests of parcels that indicated sugaring, and 2) how much do these components overlap with these forests compared to forests statewide more broadly.

Methods

Use Value Appraisal

The UVA dataset (retrieved May 30, 2025) was used to classify parcels that indicated recent sugaring activity. This was achieved by identifying records where tap counts or gallons of maple syrup were reported, where primary or secondary management activity was listed as sugarbush management, or a sugarhouse was reported on the parcel. All comment fields were also systematically reviewed to identify additional records indicating active sugaring. Recent activity was defined as any record submitted from 2015 or later and where the parcel was actively enrolled in the UVA program at the time of data retrieval.

Records were then joined to the Vermont parcel layer using School Property Account Numbers (SPANs) using parcel data retrieved February 30, 2026. For records that did not successfully join, an earlier parcel dataset (retrieved February 1, 2025) was used to link UVA data to appropriate parcels.

Vermont Conservation Design

From this inventory of parcels where sugaring was recently indicated, ecological context was determined using the VCD component layers. Landscape level components included regions identified as Habitat Blocks and Wildlife Corridors, Interior Forests, Forest Connectivity, Geological Diversity, and regions of Surface Water and Riparian Connectivity. Species-level components included areas mapped Natural Communities, Rare, Threatened, Endangered, and Uncommon plant and animal species, Wildlife Road Crossings, Vernal Pools, and Aquatic Habitat. For information about each component, see **Table A1** and **A2**. VCD layers were retrieved from the Vermont Agency of Natural Resources BioFinder portal on January 2, 2026.

VCD categorizes each component as areas of either *Priority* or *Highest Priority* conservation. These distinctions allow for a more focused assessment of where the most critical wildlife habitat occurs throughout the state, as well as additional areas that contribute to the Vermont's ecological functionality. Where two component layers were combined (Surface Water and Riparian Connectivity as well as Rare, Threatened, Endangered, and Uncommon plant and animal species), any overlapping areas were assigned the more critical designation, with *Highest Priority* taking precedent over *Priority*.

Species Movement

For additional ecological context, statewide wildlife movement maps generated by Drasher et al. (2025) were also used to evaluate sugarbush distribution across the landscape. These maps were generated using Omniscape, a circuit theory-based connectivity modeling approach implemented through the Omniscape software package (McRae et al. 2016; Landau 2020), which incorporates species occurrence and land cover data to estimate relative movement capacity across the landscape based on a species' affinity or resistance to a given cover type by modeling landscapes as conductive surfaces through which movement potential flows similarly to electrical current. The wildlife species included in this evaluation were American black bear, American marten, bobcat, coyote, moose, and white-tailed deer.

To mirror VCD designations of *Priority* and *Highest Priority*, Species Movement values were classified into five equal quantiles. Values within the top quantile (80-100%) were classified as *Highest Movement*, while areas within the upper-middle quantile (40-80%) were classified as *Movement*. Although the American marten movement map is a less refined Omniscape model than the others, it is included to examine the more conservative movement estimate of this rare Vermont mammal.

Spatial Analysis

Forested area within each parcel was first identified using the Vermont Center for Geographic Information (VCGI) 2022 tree canopy layer (resolution 0.5 m). Although these sugared forests are represented as circles in the following analysis, the actual forested extent was evaluated within each parcel.

Vermont Conservation Design and Species Movement

VCD components and Species Movement layers were then intersected with the forested area within parcels that indicated sugaring (**Figure 5**). Each VCD component and Species

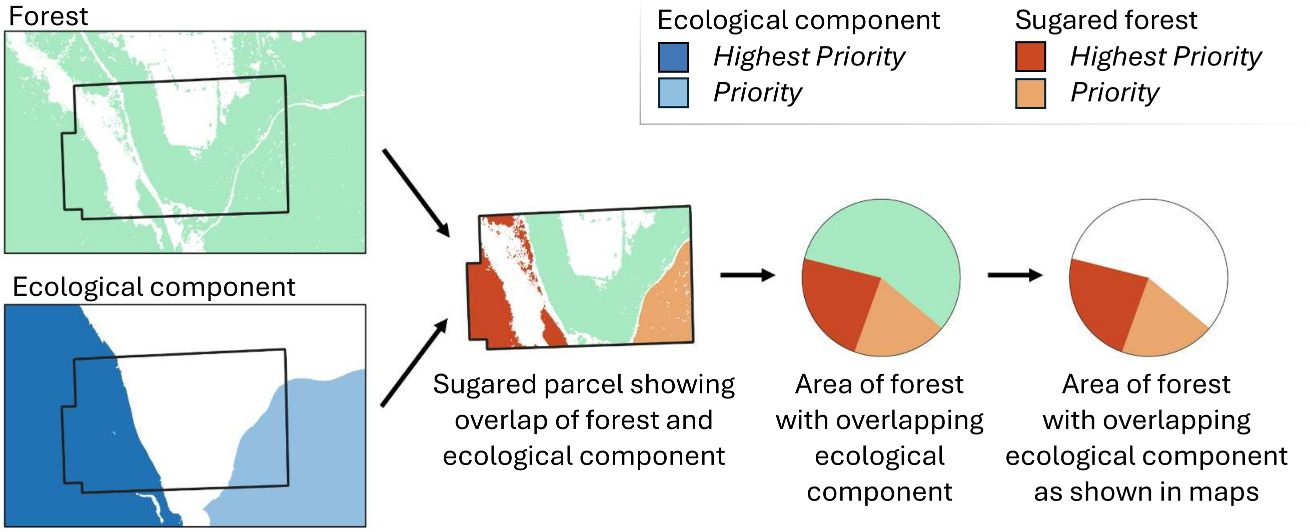

Figure 5. Workflow for calculating area of an ecological component that overlaps with forest of a parcel that indicated sugaring, where the size of the circle is equivalent to the area of the parcel's forest. A component's highest priority area (darker blue) that overlaps the parcel's forest is represented with darker orange, while a component's priority area (lighter blue) that overlaps the parcel's forest is represented with lighter orange.

Movement layer was also evaluated across land area statewide to allow for comparison between forest within parcels that indicated sugaring and their broader overall distribution throughout Vermont. Statewide land area excluded water, but included land delineated as wetland. Specifically, all water from the VCGI Vermont Hydrography Dataset water layer (retrieved February 5, 2026) was subtracted from the total area of each county (VCGI VT counties 2025B, retrieved December 30, 2025) except for water that overlapped with mapped wetlands (Bio4_Wetlands). Statewide estimates of VCD and Species Movement were then calculated across this resulting land and wetland area.

Forests, Geology and Soils, and Topography

To better understand habitat in forests managed by sugarmakers, forest type, geology and soils, and topography were characterized within parcels that indicated sugaring. This information helps characterize the natural communities and wildlife habitat present in these locations.

Across all non-open water areas within these parcels, the 2024 LANDFIRE Existing Vegetation Type (EVT; U.S. Geological Survey 2024) layer (30 m resolution) was used to summarize vegetation types. An exploration of UVA records was also conducted to characterize information about forests within parcels that indicated sugaring, including forest stand types, firewood removal by species, and forest management activities listed.

Within the forest of parcels that indicated sugaring (referred to in this report also as 'sugared forests'), bedrock (Ratcliffe et al. 2011) and surficial geology (Vermont Geological Survey 2008) were summarized. Soil characteristics were also extracted from the Web Soil Survey, including soil component name, runoff potential, drainage class, percent composition, organic matter content, depth to restrictive layer, pH, and cation exchange capacity. Values were calculated as the area within forest of parcels that indicated sugaring and weighted by proportion of each soil component within the given area.

Topography, including elevation, aspect, and slope were summarized using the Vermont LiDAR-derived raster datasets (2013-2017; 70 cm resolution). Elevation of Northern Hardwood Forests was determined by randomly generating 100,000 points within the LANDFIRE EVT layer to determine elevation of Northern Hardwood Forest relative to forests within parcels that indicated sugaring. Aspect was also evaluated statewide using 100,000 randomly generated points across Vermont.

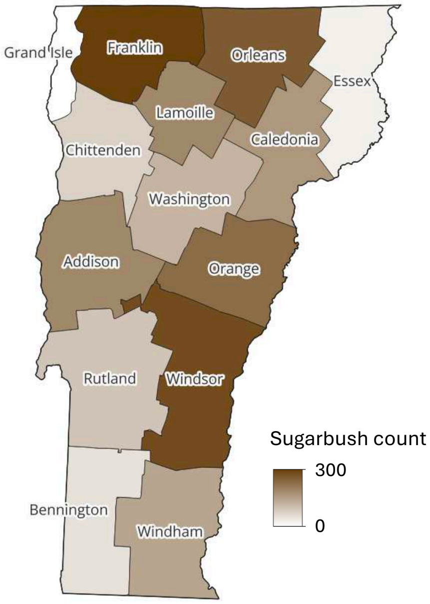

Figure 6. Sugarbush count where a parcel's forest is primarily within the given county.

Results

Use Value Appraisal

Of the 21,722 parcels listed in the UVA dataset, 2,352 (10.8%) indicated sugaring. Of these, 2,145 parcels (9.8%) were actively enrolled and most recent data indicated sugaring from all records submitted between 2015 and 2025. From the variables used to determine active sugaring, sugarhouses identified 26.7% records (n = 573), sugarbush management identified 24.6% (527), taps or gallons identified 16.4% (351), and notes identified 3.9% (84). The remaining 28.4% were identified by a combination of these variables. When joined with the parcel layers, 34 parcels were unmatched, leaving 2,111 parcels that indicated sugaring (**Figure 6**). From the UVA dataset, tap count ranged from 15-125,000 with median tap count of 1,600 taps per parcel and an average tap density of 176.7 ± 279.6 taps/ha (71.5 ± 113.2 taps/ac).

Parcel, Forest, and Sugarbush Size

Total forest within parcels that indicated active sugaring accounted for 7.7% (139,510.9 ha; 344,738.9 ac) of Vermont's total forestland (1,842,799.1 ha; 4,553,655.8 ac). Each parcel that indicated sugaring was 84.2 ± 140.6 ha (208.1 ± 347.5 ac) and 77.3 ± 20.3% forested (66.1 ± 126.8 ha; 163.3 ± 313.4 ac). Forest within each parcel was classified as 71 ± 18.5% deciduous and 29 ± 18.5% coniferous. Sugarbush stands within each parcel were 29.4 ± 51.5 ha (72.7 ± 127.2 ac; 44.5 ± 33.5% of a parcel's forest or 34.9 ± 30.7% of the parcel). From these values, sugarbush stands accounted for an estimated 3.4% (0.9-5.9%; 15,346.1-107,818.6 ha; 37,921.3-268,896.3 ac) of Vermont's forests.

Vermont Conservation Design

Landscape Components

Highest Priority for all VCD landscape components within parcels that indicated sugaring were 6.7-7.6% of their overall components, except for Surface Water and Riparian Connectivity which was 3.7% (**Figure A1**). Habitat Blocks and Wildlife Corridors showed high overlap between the statewide mapped component and the forests of parcels that indicated sugaring (7.6% *Highest Priority*), and the most proportion of forest that includes the component (90.8% of sugared forests included *Highest Priority* and *Priority* combined; **Figure 7**).

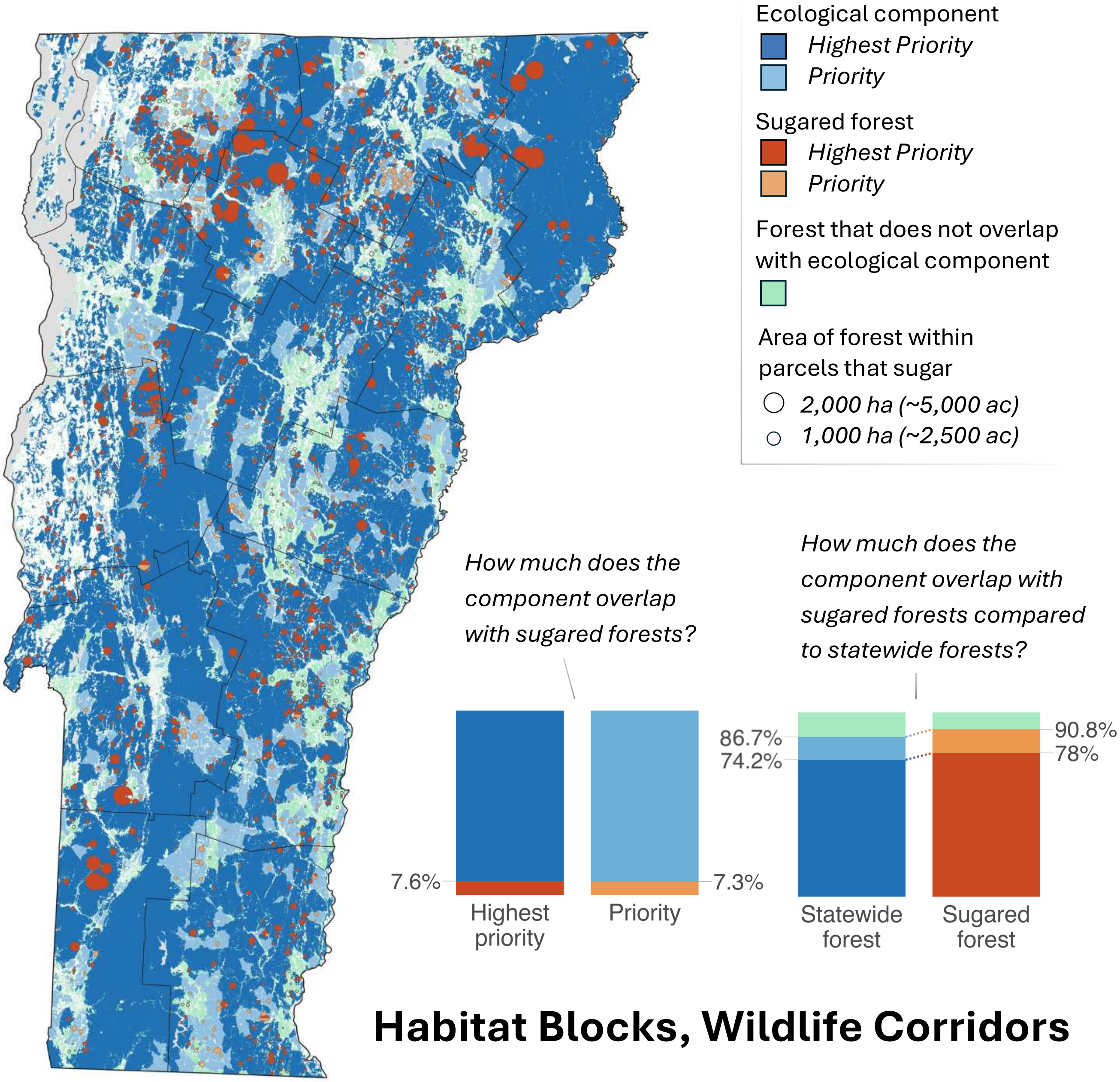

Figure 7. Habitat blocks and wildlife corridors (blue) and overlap with forests of parcels that indicated sugaring (orange).

Of all VCD and Species Movement layers examined, *Highest Priority* landscape components showed the greatest association with forests of parcels that indicated sugaring, with Overall Landscape Component the highest relative to statewide forests (+37.9%), followed by forest connectivity (+30.1%), and interior forest (+28.7%). The most frequent individual VCD components found in sugared forests were Habitat Blocks and Wildlife Corridors (90.1%), Surface Water and Riparian Habitat (89.9%), Interior Forest (77.4%), and Forest Connectivity (74.4%).

Species Components

At the species level, vernal pools mapped across the state showed the greatest proportional overlap with sugared forests than any other VCD or Species Movement layers (**Figure 8; Figure A2**), with 9.2% of all *Highest Priority* vernal pool area occurring in sugared forests. Alternatively, only 9.9% of sugared forests included mapped vernal pools, the lowest frequency of all variables examined.

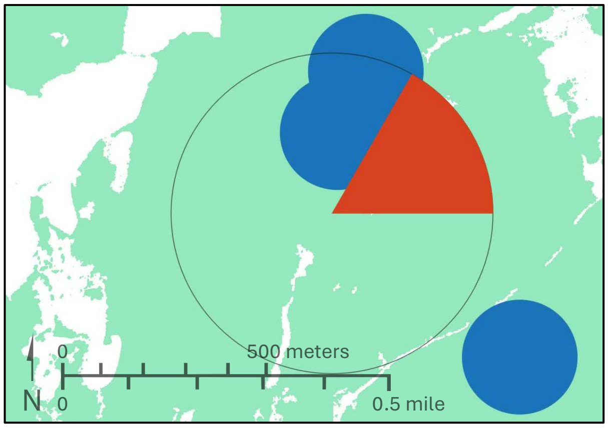

Figure 8. Vernal pools (blue) and proportion that they intersected the forest of a parcel that indicated sugaring (orange).

The VCD species components composed a small percentage of forests both statewide and within sugared forests with equal proportions (**Figure A2**). The Overall Species Component accounted for the most area within sugared forests (10.8%), followed by rare, threatened, endangered, and uncommon species (4.3%), and natural communities (2.9%).

Species Movement

Across all species, *Highest Movement* occurred within 5-8.2% of forests of parcels that indicated sugaring. Specifically, of all *Highest Movement* mapped statewide, bobcat overlapped most with sugared forests (8.2%; **Figure 9**) followed by American black bear (7.8%), coyote (7.7%), moose (7.5%), and white-tailed deer (7.2%). Across all forest within parcels that indicated sugaring, bobcat movement (combined *Highest Movement* and *Movement*) was highest, overlapping with 87.3% of all sugared forests with nearly half of these forests (48.2%) classified as *Highest Movement*. Coyote, American black bear, moose, and white-tailed deer had similar overlap with sugared forests, ranging from 86.2-82% overall overlap and 46.2-42.3% overlap of *Highest Movement* for each species. The relative proportion of overlap was greater for all these species in sugared forests compared to forests statewide, with *Highest Movement* areas disproportionately occurring within sugared forests. Specifically, valuable movement areas for bobcat disproportionately occurred within sugared forests relative to forests more broadly (+11.9%), followed by coyote (+9.5%), American black bear (+7.7%), and white-tailed deer (+6.7%).

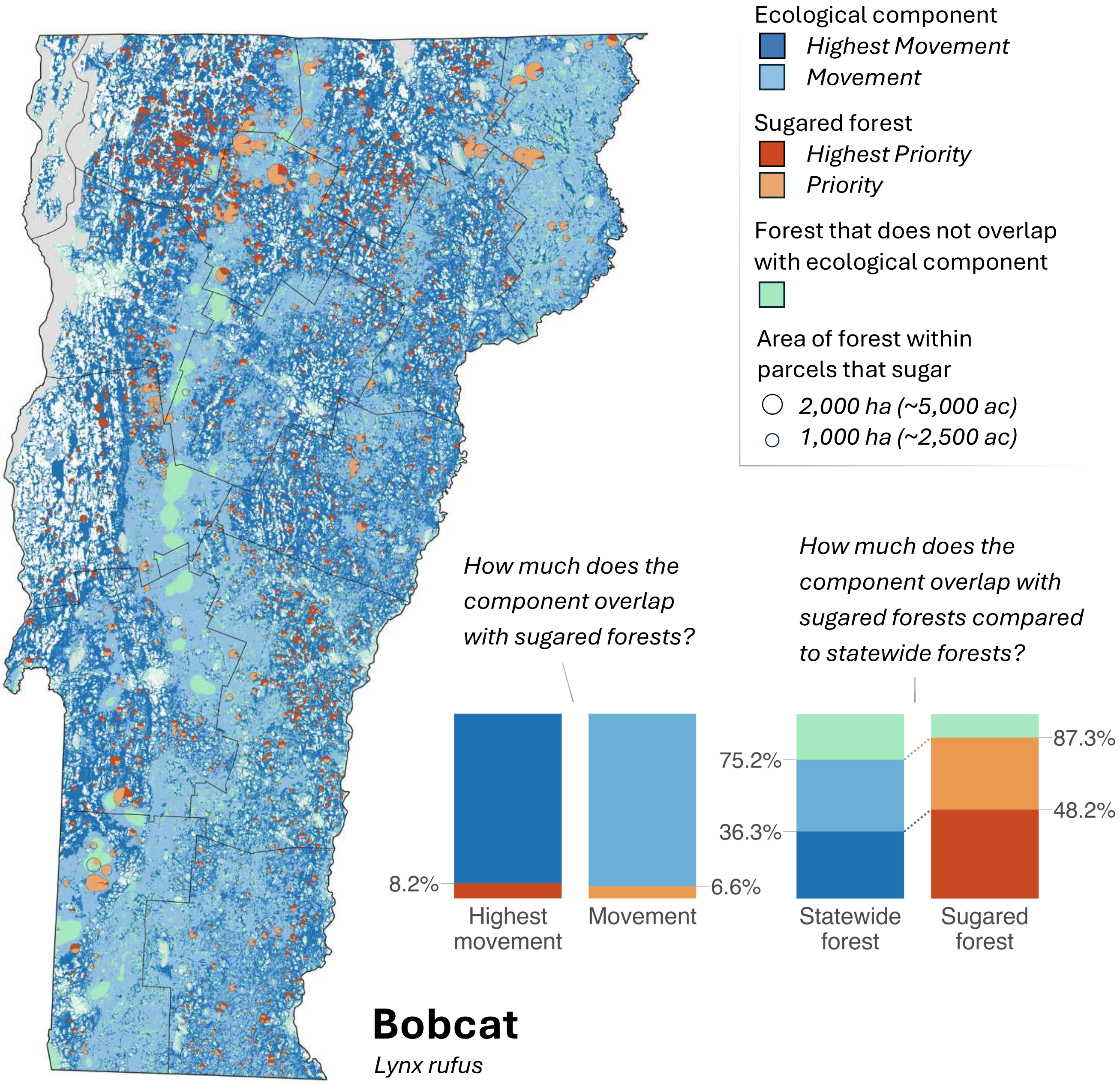

Figure 9. Bobcat movement areas (blue) and overlap with forests of parcels that indicated sugaring (orange).

Of all components examined, Species Movement layers overlapped most frequently with these forests, particularly for bobcat (99.8% of sugared parcels contained any amount of bobcat movement areas in their forests), coyote (99.7%), white-tailed deer (99.5%), moose (94.8%), and American black bear (94.4%; **Table A3**). Only 25% of sugared parcels contained any amount of American marten movement areas in their forests (**Table A3**), reflecting the more restricted distribution and habitat requirements of this species across Vermont.

Forests, Geology and Soils, and Topography

Forests

LANDFIRE Forest Type

Parcels that indicated sugaring were composed of 51.4% Northern Hardwood Forest, 11.9% pasture and hayland, and 4.8% Pine-Hemlock-Hardwood Forest (**Table A4**) using the US Forest Service LANDFIRE forest type name classifications.

UVA Forests

Of the actively enrolled parcels that indicated sugaring, 1,008 (47%) contained stand-level data, with information about forest type, forest management practices including species removed for firewood, and sugarbush size.

Stands with Sugarbush Management

From the 2,989 stands where Management Activity on the UVA form included sugarbush management, stand types were identified as 40.2% sugar maple, 36.6% beech, birch, sugar maple, and 12.8% mixed wood (25-65% softwood; **Table A5**). Of these stands, 70.1% were characterized as even-aged stands, where trees generally grow as a single age class, while 29.9% were characterized as uneven-aged stands. For these stands where sugarbush management was listed, 66.1% stands listed no other management activity, 4.4% listed crop tree release, 3.7% listed single tree selection, 3.3% listed invasive species control, and 3.2% listed intermediate thinning (**Table A6**). Productivity for these stands was primarily excellent (49.5%) or good (47.2%), with stand basal area 23 ± 9.9 m^2/ha (100.2 ± 43.3 ft^2/ac).

Firewood Removal

From the Forest Management Activity Report data (parcel-level, n = 869), 35% of the parcels that listed firewood removal listed removal of ash spp., 27% listed removal of maple spp., 16.9% listed removal of birch, and 10.8% listed removal of American beech (**Table A7**). Most did not list a firewood species (59.3%).

Geology and Soils

Within sugared forests, bedrock was primarily phyllite (32.5%), muscovite-schist (15.2%), and quartzite (11.5%; **Table A8a**) under surficial geology of glacial till (85%; **Table A8b**). Soils within these forests were 22.2 ± 22.6 cm deep (8.7 ± 8.9 in; **Figure A4a**) and primarily classified as well drained (52.4%), somewhat excessively drained (20.8%), and moderately well drained (13.9%; **Table A9c**). Composition was 51.3 ± 16.1% sand, 42.1 ± 15% silt, and 6.6 ± 5.9% clay (**Table A9d**) with additional organic matter content of 8.1 ± 21.3% (**Figure A4b**). These soils had a pH of 5.6 ± 0.5 (**Figure A4c**) and cation-exchange capacity of 9.9 ± 18.7 cmol(+)/kg (**Figure A4d**).

Topography

Forests within parcels that indicated sugaring occurred at 358.2 ± 130.3 m (1,175.1 ± 427.6 ft) elevation, at the lower edge of Northern Hardwood Forests 447.6 ± 170.4 m (1,468.4 ± 559.1 ft; **Figure 10**). These sugared forests primarily faced east (20.1%) or west (14.4%; **Figure 11**) with an average slope of 20.3 ± 6.8°.

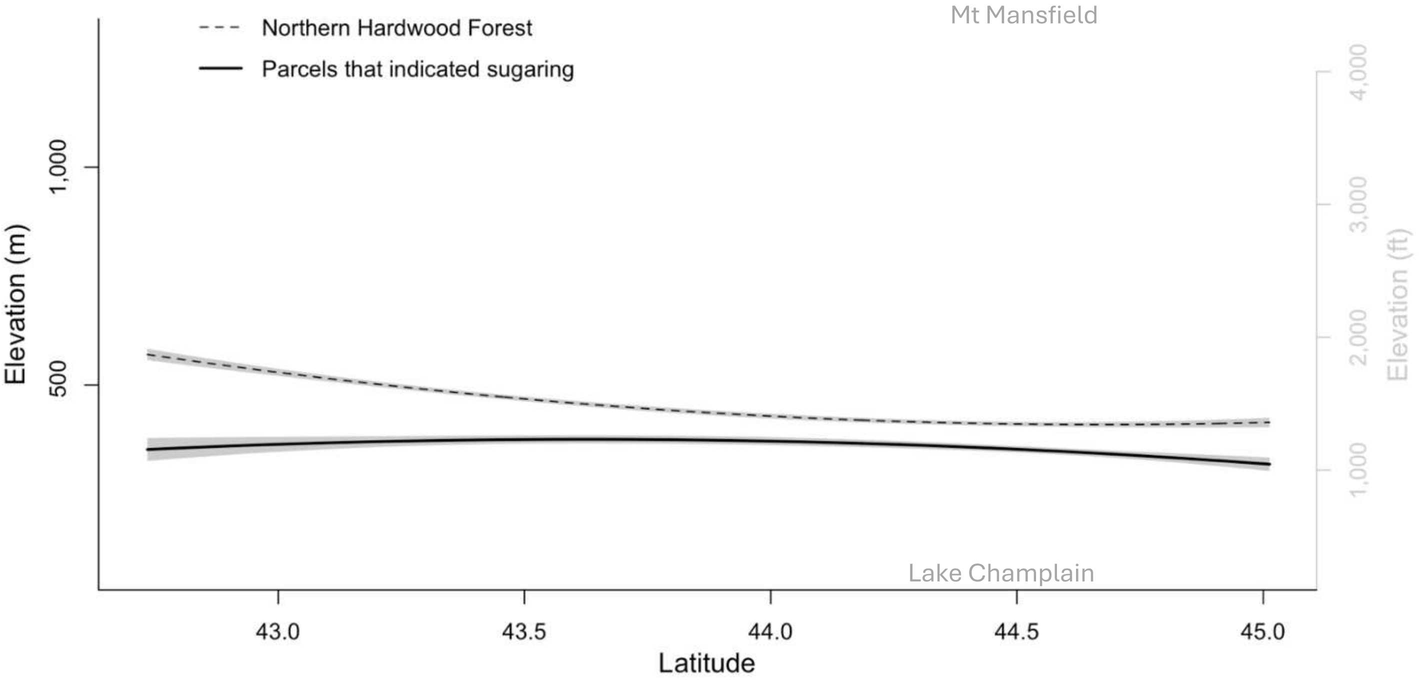

Figure 10. Average elevation of forest within parcels that indicated sugaring and Northern Hardwood Forest from US Forest Service LANDFIRE dataset. Best fit lines plotted with 95% confidence interval. The Y axis spans from Lake Champlain (30 m; 98 ft elevation) to Mt Mansfield (1,340 m; 4,395 ft), showing the lowest and highest elevations of Vermont.

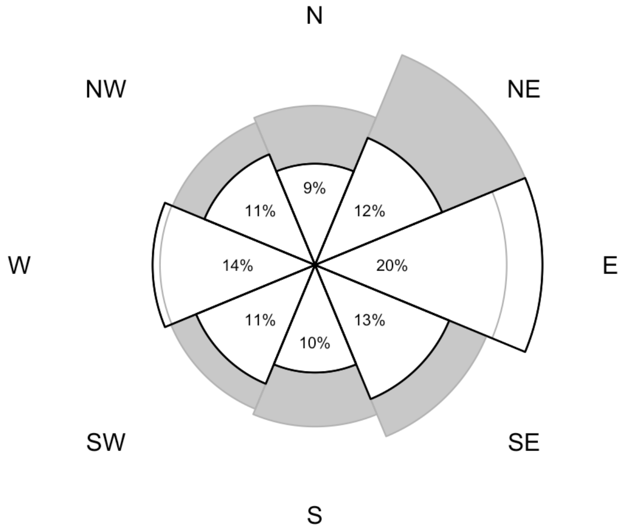

Figure 11. Aspect of forests within parcels that indicated sugaring, with statewide aspect (gray).

Discussion

Sugaring in Vermont represented a small portion of the forested landscape, but occurred in areas identified by Vermont Conservation Design for their high quality ecological functionality. While approximately 7.7% of Vermont's forest overlapped with sugared forests, stand-level information suggested ~3.4% was actively used for sap production. Although this is a relatively small percentage, and acknowledging that some sugar-makers were missing from the dataset or no longer sugar, this represented a meaningful area of forestland (15,346-107,818 ha; 37,921-268,896 ac) distributed across the state.

These sugared forests identified from the UVA dataset overlapped substantially with ecologically valuable habitat blocks and wildlife corridors, including forests suited for wildlife that require landscape-level dispersal and large blocks of unfragmented forests. These qualities, interior forest and forest connectivity, were both found disproportionately within sugared forests relative to forests statewide, with over 80% of all forest managed by sugarmakers identified for its ecological value in this respect. Such findings were also reflected in the examination of Species Movement models, where valuable movement areas disproportionately overlapped with sugared forests, particularly for bobcat, followed by coyote, American black bear, and white-tailed deer. Similarly, over 80% of forest managed by sugarmakers provided valuable movement potential for these species.

With the vast majority of sugarmakers stewarding forests that contained areas of ecologically valuable forestland, decisions around sugaring infrastructure (such as tubing networks) as well as forest structure and composition remain important in determining how effective these forests are in supporting habitat and dispersal opportunities for wildlife, with the greatest importance being that these areas remain forested as they have.

Although the species-level components are less striking on a statewide map, they provide valuable insight into ecologically important features at more localized scale. Vernal pools, for example, showed the greatest overlap with sugared forests of any species-level component, where 9.2% of all statewide *Highest Priority* vernal pool area occurred within these sugared forests, the most of all components examined. While only 9.9% of sugarmakers had a mapped vernal pool within their forest, the lowest proportion of all variables examined, this underscores their rarity and the importance of maintaining forests that support vernal pools. Additionally, not all vernal pools are mapped statewide, and vernal pools within sugared forests are likely more widespread than represented in this assessment. Aquatic habitat followed a similar pattern, which accounted for 3.9% of the total mapped non-open water aquatic habitat statewide, representing the second largest species-level component within sugared forests. This relatively high overlap of vernal pools and aquatic habitat with sugared forests further highlights the importance of wet or aquatic areas as ecologically valuable within these sugared forests. In contrast, wildlife road crossings showed relatively low overlap with sugared forests, likely due to how the component is mapped (buffering 75 m (246 ft) on either side of roads intersecting high-quality forest). Despite this, the Wildlife Road Crossing component intersected 27% of sugarmaker forests, indicating that movement of wildlife across roads remains a relevant consideration as well.

At the stand level, sugarbushes are typically productive Northern Hardwood Forests shaped by conditions like moderately deep, moist, well-drained soils on the lower elevation toe slopes of Vermont's hillsides, often with east- or west-facing aspects. These are naturally sugar maple-dominated localities (Leak 1982; Thompson et al. 2019), with sugarmakers generally working within forests that support high sugar maple composition, rather than converting forests into that condition. This is further reflected in the UVA data, where forests were reported to be primarily sugar maple or beech-birch-sugar maple forests, and maple making up 27% of trees removed for firewood, just under ash (35%) which has been removed more rigorously in anticipation of widespread mortality caused by the emerald ash borer (Higgins et al. 2025).

Forest structure where sugarbush management occurs was reported as approximately 70% even-aged stands with most common additional management practices recorded as crop tree release, single tree selection, invasive species control, and intermediate thinning. While sugarbush management is not explicitly defined, Isselhardt et al. (2022) characterize sugarbush management as single-tree selection (58%), crop tree release (29%), small group selection (~7%) and shelterwood systems (~7%). Together, this suggests that many forests that are predominantly even-aged stands are being cultivated into more diverse, uneven-aged structure through sugarbush management.

From this landscape- and parcel-scale exploration, sugaring emerged as a land use occurring within high quality sugar maple-dominated natural communities, while also overlapping with Vermont's most biologically important areas. If impacts from sugaring operations exist, areas of more concentrated sugaring activity may be areas where the collective influence of such land use is greatest, such as across Franklin, Lamoille, Orleans, and Windsor counties, at the foothills of Mt Abe, and in more isolated locations along the Taconic Range and within the Northeast Kingdom. Throughout these areas, a multiple-property approach, where neighbors work with neighbors to create wildlife-friendly corridors, high in structural diversity including understory cover (Hilty et al. 2019), or to encourage habitat for those species that are rare and require the most support to persist on our shared landscape (**Table 1; Table 2**; **Table 3**), can have the greatest impact, if such collaboration is not happening already.

Chapter 3: Field Assessment of Sugarbushes

Introduction

This field assessment examines the pieces – the features of the forest on the ground and the wildlife that move among them. I approached this chapter as a shift away from spatial analysis to be able to walk through these forests with wildlife in mind, setting up cameras and audio devices and measuring vegetation and other habitat features, in an effort to answer questions that emerged when I began this project. How diverse are these sugarbushes? Are there saplings filling the understories, large holes in larger trees providing shelter? Is there shelter under slash piles? Are there pools of water in these forests for amphibians? For birds? For bear and moose? Do the tubes in these sugarbushes limit movement of wildlife across the landscape?

I designed this field assessment to address these questions and provide preliminary insight into wildlife habitat within sugarbushes that varied in size and geographic distribution across Vermont. I collected data on vegetation, the forest structure and species composition of trees, as well as habitat features for the many amphibians, reptiles, birds, and mammals found in Northern Hardwood Forests. I counted taps and measured sap lines while examining distribution of wildlife. Specifically, I surveyed one core and one edge plot at twenty sugarbushes to assess whether wildlife detections from camera traps and audio devices differed between the center of sugarbushes relative to the perimeter, under the hypothesis that reduced detections in the core indicate that cumulative interaction with tubing limits wildlife movement and deters habitat use within sugarbushes. This design allowed differences in wildlife detection to be attributed to variation in sugaring intensity or site-level habitat features, if differences existed.

Methods

Site Selection

I initially solicited sugarbushes with the highest number of taps, greatest volume of sap produced, and largest sugarbush acreage as tracked by the Use Value Appraisal program. I incorporated additional sites as recommended by Proctor Maple Research Forest or the Vermont Forest Legacy Program, including leased sugarbushes on Forests, Parks and Recreation land. In total, twenty sugarbushes were selected, ranging from larger-scale sugarbushes to smaller hobby operations, with each county represented across Vermont with the exception of Grand Isle and Orleans counties (**Figure 12**). Participation in this study was voluntary, resulting in a self-selected sample; three of 23 sugarbushes declined to participate or did not respond to solicitation. Because site selection was partly based on operational characteristics such as tap

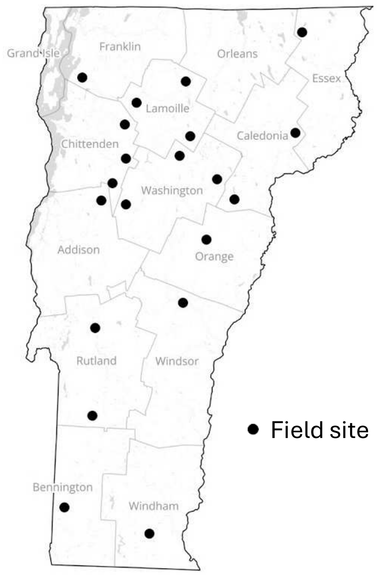

Figure 12. Sugarbushes surveyed.

count, sap production, and acreage, this sample does not represent the full range of sugarbushes occupying different ecological or landscape contexts across Vermont.

Plot Configuration

At each site, I established one core plot and one edge plot. Using maps provided by the sugarmaker, I generated the core plot at the geometric center of the sugarbush and randomly generated the edge plot 15 m inside the sugarbush boundary where it bordered similar forest, as determined from satellite imagery. Where sugarbushes were not mapped, plot locations were generated using forested areas within the property boundary, with the core plot placed at the center of the largest contiguous forest tract and the edge plot located 15 m inside the forest perimeter where the property bordered similar forest. Once on the ground, I walked sections of the sugarbush perimeter to verify estimated boundaries and adjusted plot locations where mapped and on-the-ground boundaries differed. Because sugarbushes often did not extend to their mapped boundaries, edge plots were repositioned as needed by walking either toward or away from the sugarbush center so they remained consistently 15 m inside the sugarbush edge, defined by the outermost tubing. Elevation difference between core and edge plots did not exceed 100 m.

Field Protocol

Sample Plots

Each plot was a 11.35-meter radius (⅒ acre) circular plot. I adapted the plot design from Klockow et al. (2013), which is comparable to United States Forest Service Forest Inventory and Analysis Program (USFS FIA) plot dimensions while also providing adequate nested sampling. The design used for this survey (**Figure 13**) was recommended by Morse (2025) after their four seasons of fieldwork.

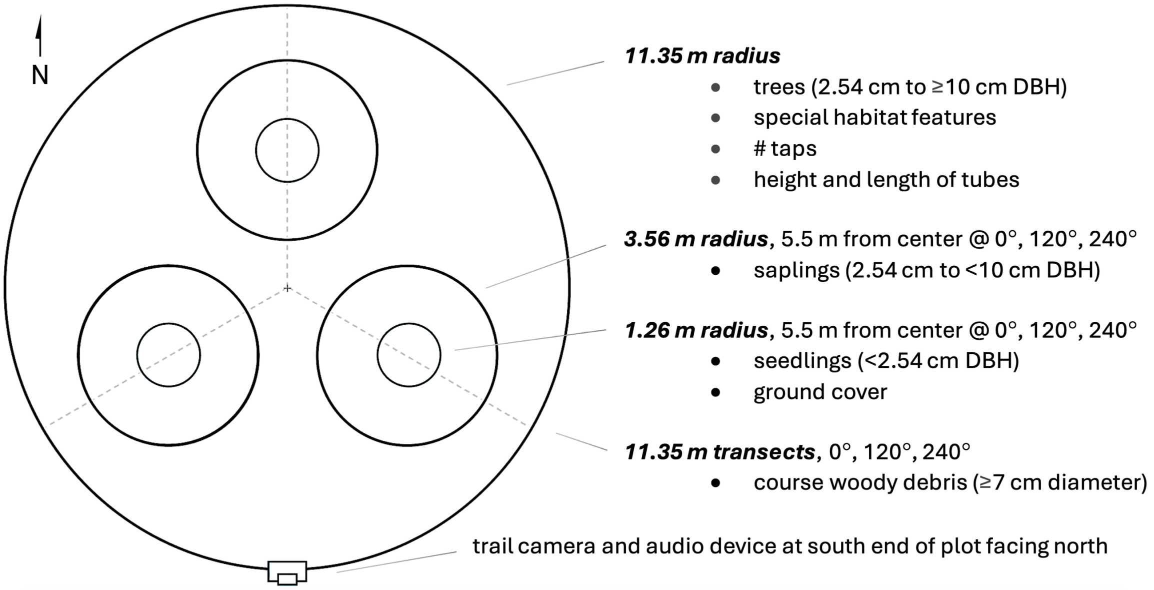

Figure 13. Sample plot layout showing locations where trees, saplings, seedlings, ground cover, and special habitat features were recorded, along with number of taps and tubing height and length.

Within each plot, I collected data to characterize available habitat for wildlife. Specifically, I noted special habitat features, including tree size classes and standing dead trees (**Figure 14**), natural communities, coarse woody debris, and ground cover, as well as taps and tubes and detection of wildlife.

Figure 14. Standing dead tree in a sugarbush in Royalton, Vermont.

Habitat

Special Habitat Features

Special habitat features were recorded within each plot to assess site-level habitat suitability for wildlife across sugarbushes. A set of 25 site characteristics (**Table 4**) was derived from *Technical Guide to Forest Wildlife Habitat Management in New England* (DeGraaf et al. 2006) and selected to represent habitat requirements for 204 wildlife species occurring in Northern Hardwood Forests of Vermont (Vermont Natural Heritage Inventory 2025a, 2025b, 2025c). Most features on this list were examined by systematically measuring trees, coarse woody debris, and ground cover within each sample plot. Other features were surveyed as presence-absence within the plot and complemented by reference photos and notes, like dimensions of the hole for *tree cavity*, height for *root tip up*, or percent cover for *deer yard*.

Table 4. Special habitat features adapted for survey from DeGraaf et al. (2006) for mammals, birds, amphibians, and reptiles of Vermont's Northern Hardwood Forests.

Forest composition
- Tree size classes
- Tree species composition
- Natural community
- Forest edge
- Deer yard

Shelter and perches
- Rock ledge
- Talus or rock crevices
- Hole in ground
- Root tip up
- Coarse woody debris
- Slash pile
- Loose bark
- Tree cavities
- Standing dead tree

Human survey
- Structures
- Road
- Site grazed

Ground Cover
- Herbaceous cover
- Rocky ground

Water
- Seep or wet ground
- Vernal pool
- Flow (none/stream/river)
- Aquatic vegetation
- Contains fish

Forest Composition

Within each plot, I measured diameter at breast height (DBH; 1.37 m; 4.5 ft) for all woody plants ≥10 cm DBH identified to species. Saplings (≥2.54 cm to <10 cm DBH) were identified to species and measured for DBH within three 3.56 m radius subplots located 5.5 m from the plot center at bearings of 0°, 120°, and 240°. Trees were categorized into size classes using thresholds described by DeGraaf et al. (2006; **Table 5**). Seedlings (<2.54 cm DBH) were counted and identified to species within three 1.26 m radius subplots (**Figure 13**), sharing a center with the sapling plots. I used the vegetation data and surrounding topography to determine natural community type present at each sample plot using *Wetland, Woodland, Wildland: A guide to the natural communities of Vermont* (Thompson et al. 2019). Ecoregions were also documented for each plot using the EPA Level IV ecoregion layer (EPA 2012).

Table 5. Tree size class categories with diameter at breast height (DBH) thresholds as described by DeGraaf et al. (2006).

Size class	Hardwood DBH (cm)	Softwood DBH (cm)
Sapling-poletimber	2.54 - 27.68	2.54 - 22.60
Sawtimber	27.69 - 60.95	22.61 - 50.79
Large sawtimber	>60.96	>50.80

Coarse Woody Debris

Coarse woody debris was sampled along three 11.35 m (37.24 ft) transects extending from the plot center at bearings of 0°, 120°, and 240°. As described in the USFS FIA protocol (Woodall and Williams 2007), all fallen woody material ≥7.62 cm (3 in) in diameter that intersected a transect was recorded, with measurements of diameter and length taken for each piece, as well as decay class (1 = no decay, 5 = severely decayed) and species if distinguishable.

Ground Cover

Ground cover within seedling subplots was estimated ocularly as the percent cover of rock, woody debris, herbaceous vegetation, and ground substrate (leaf litter and exposed soil), with categories constrained to sum to 100%, similar to methods from Law et al. (2001). These methods were designed to capture special habitat feature requirements for wildlife that prefer “rocky forest floors,” “herbaceous cover,” or “bare ground” as described by DeGraaf et al. (2006). A list of all herbaceous species was also recorded to assist in identifying the natural community of a plot.

Sugaring Infrastructure

Taps and Tubes

To see if taps or tubing correlated with wildlife detections, I recorded number of taps for each tree as well as total tubing length and minimum and maximum height from the ground for each tube segment within the 11.35 m (37.2 ft) radius plot. Although lateral tubing is smaller (diameter of 0.48-0.79 cm; $\frac{3}{16}$-$\frac{5}{16}$ in) and more flexible, while mainline tubing that connects the lateral lines to the sugarhouse is larger (diameter of 1.9-10.2 cm; ¾-4 in) and more rigid, tubing was not distinguished between lateral and mainline categories for this assessment.

Roads

Roads were digitized within 100 meters (328.1 ft) of plot center as any track discernible from 35 cm resolution hillshade imagery. These tracks included active and inactive forest roads that could be passable using truck or ATV. Though wildlife species can be influenced by roads up to 5 km away (Benítez-López et al. 2010), 100 meters was used to prevent overlap between core and edge plots.

Wildlife

Mammals

Browning Elite HP5 (8EHP5) trail cameras were deployed at the south end of each plot, facing north. The cameras were programmed to record 5-second video clips following each infrared movement trigger within a 30-day window, with staggered deployment July 1 through September 9, 2025.

Birds

Song Meter Micro 2 were deployed at the south end of each plot facing north. Devices were programmed to capture audio for 10 minutes every half hour from 5AM to 9AM over a 5-day window with staggered deployment July 1 through September 1, 2025. Species were then

Figure 15. Black-throated blue warbler lands on an American beech sapling in a sugarbush in Johnson, Vermont.

detected using BirdNet v2.4 with parameters set for community-level analysis, including 0.5 sensitivity, 2 second overlap, and 0.5 minimum confidence (Pérez-Granados et al. 2025). The week of the year when each recording took place (from week 27 to 35) was set as a parameter as well as latitude and longitude of each plot with minimum occurrence probability for a species to be included set to 0.02 (Pérez-Granados et al. 2025).

I also examined a subset of the audio (200 plot-days from 7:00AM) to evaluate error rate.

Analysis

Differences in wildlife detections, tree diversity, coarse woody debris, tap density, and tube lengths between core and edge plots were tested using either paired t-tests (t.test() in R) or paired Wilcoxon signed-rank tests (wilcox.test()) when data were found to not be normally distributed based on the Shapiro-Wilks test (shapiro.test()). Differences in the presence or absence of coarse woody debris were also tested using chi-square tests (chisq.test()).

Tap density, tube length, and tree diversity were also evaluated using Pearson correlation tests (cor.test(method="pearson") to assess linear relationships between these variables.

Tree diversity was quantified using the Shannon diversity index, with tree species diversity binned by basal area of each species and tree structure binned by basal area of each size class; sapling-poletimber, sawtimber, and large sawtimber size classes (**Table 5**). Shannon diversity was calculated as $-\sum(p \times \log(p))$, where p is the proportion of basal area within each group (1-9 species; 3 structure classes).

To test relationships between mammal and bird detections and plot variables, I used Spearman correlation tests (cor.test(method = "spearman")) for non-parametric relationships with mammal and bird detections as response variables and tap density, tube length, road density, elevation, slope, tree species diversity, structural diversity, and basal area by size class (sapling-poletimber, sawtimber, and large sawtimber) as predictor variables.

To determine if sample size was adequate to detect relationships given the observed variability of the variables, I conducted a power analysis using power.t.test() in R.

Results

Habitat

Special Habitat Features

Tree cavities and standing dead trees were the most common features surveyed, each occurring in 15% (n = 6) of plots, followed by slash piles in 12.5% (5), holes in the ground in 10% (4), talus or rock crevices in 7.5% (3), and loose bark in 7.5% (3). Root tip-ups, seep or wet ground, deer yards, and streams each occurred in 5% (2) of plots. No plots included rock

Figure 16. Sugar maple seedlings on the forest floor of a sugarbush in Washington, Vermont.

ledges, forest edges, tall perches by water, vernal pools, aquatic vegetation, or waterbodies containing fish.

The openings of holes in the ground and tree cavities did not exceed 10 cm (3.9 in) diameter, while the loose bark recorded did not protrude from the tree more than 2 cm (0.8 in). Slash piles recorded were typically small fallen trees that provided minimal shelter.

Forest Composition

Sugarbushes were predominantly sawtimber stands, with 80% (n = 32) of plots contributing majority of basal area from sawtimber-sized trees, followed by 12.5% (5) from sapling-poletimber, and 2.5% (1) from large sawtimber. The remaining 5% (2) of plots were classified as uneven-aged with no tree size class contributing >50% basal area. Overall, sawtimber-sized trees accounted for 51.8% of all basal area measured (23.1 m^2 per ha; 100.8 ft^2 per ac), while large sawtimber trees accounted for 29.9% (13.4 m^2 per ha; 58.1 ft^2 per ac from 11 trees), and saplings accounted for 18.3% (8.2 m^2 per ha; 35.6 ft^2 per ac). Sawtimber was over 90% of basal area in 10% (n = 4) of plots. In total, average basal area across all size classes was 44.6 m^2 per ha (194.5 ft^2 per ac) from live stems ≥2.54 cm (1 in) DBH.

American beech was the most common live sapling species (318.6 stems per ha; 128.9 stems per ac) followed by sugar maple (190; 76.9, eastern hophornbeam (183.4; 74.2), red spruce (72.5; 29.4), and yellow birch (71.5; 28.9). Sawtimber trees were primarily sugar maple (112.4; 45.5), with red maple (19.8; 8), white ash (14.2; 5.7), and yellow birch (13; 5.2). Large sawtimber were sugar maple (5.6; 2.2), red maple (0.6; 0.2), and black cherry (0.6; 0.2). By basal area, sugar maple contributed the most (19.5 m^2 per ha; 84.8 ft^2 per ac), followed by red maple (3; 13.1), and yellow birch (2.3; 10.2), with sugar maple not exceeding 75% basal area of all live trees measured over 12.7 cm (5 in) DBH (**Figure 17**), though sugar maple was over 90% of basal area in 22.5% (n = 9) of plots.

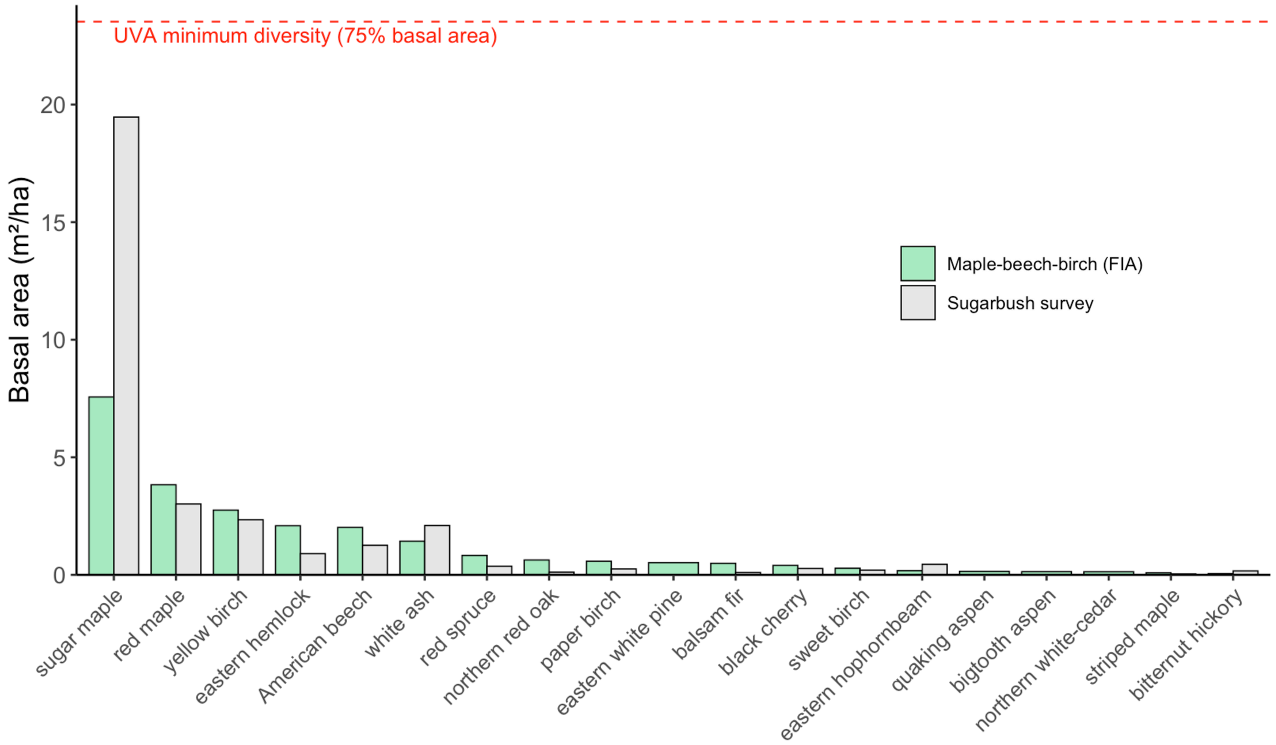

Figure 17. Tree species by basal area across the sampled sugarbush sites (gray) relative to maple-beech-birch forest group estimates (green) from the US Forest Service Forest Inventory and Analysis (FIA) program. Basal area was calculated from live trees ≥12.7 cm (≥5 in). The red dotted line is the minimum diversity permitted by the Use Value Appraisal program where a single species cannot exceed 75% of total basal area of a stand.

Standing dead trees were mostly sapling-poletimber (155.8 per ha; 63 per ac), followed by sawtimber (8.6 per ha; 3.5 per ac) and large sawtimber (1.2 per ha; 0.5 per ac). Most common standing dead species were American beech (26.2 per ha; 10.6 per ac), sugar maple (22 per ha; 8.9 per ac), balsam fir (17.3 per ha; 7 per ac), and yellow birch (10.8 per ha; 4.4 per ac; **Table 6**).

Table 6. Standing dead trees ≥2.54 cm (1 in) DBH with species count.

Tree size class	Trees per ha (trees per ac)	Species
Sapling-poletimber	155.8 (63)	American beech (39.8 per ha; 16.1 per ac), sugar maple (39.8; 16.1), balsam fir (33.5; 13.6), red maple (12.6; 5.1), yellow birch (12.6; 5.1), striped maple (4.2; 1.7), white ash (4.2; 1.7), paper birch (3.7; 1.5), eastern hophornbeam (2.5; 1), eastern white pine (1.2; 0.5), eastern hemlock (0.6; 0.2), sweet birch (0.6; 0.2), unknown (0.6; 0.2)
Sawtimber	8.6 (3.5)	Sugar maple (3.7; 1.5), American beech (1.2; 0.5), yellow birch (0.6; 0.2), eastern hemlock (0.6; 0.2), red maple (0.6; 0.2), sweet birch (0.6; 0.2), white ash (0.6; 0.2)
Large sawtimber	1.2 (0.5)	Sugar maple (0.6; 0.2), yellow birch (0.6; 0.2)

Forest composition did not differ between core and edge plots, with no significant differences in Shannon diversity of size classes (paired t-test, $p = 0.14$), species diversity (paired t-test, $p = 0.37$), or standing dead tree density (Wilcoxon signed-rank test, $p = 0.75$). Standardized Shannon diversity (0-1) averaged 0.50 ± 0.24 for species and 0.51 ± 0.20 for structure, and these were positively correlated (Spearman, *rho* = 0.43, $p = 0.005$), indicating that plots with greater species diversity also tended to have greater size-class diversity.

From vegetation data and topography, the natural communities of these plots were predominantly Northern Hardwood Forest (n = 32; 80%) with 3 (7.5%) Rich Northern Hardwood plots, 3 (7.5%) Northern Hardwood Talus Woodland plots, and 1 (2.5%) Red Spruce-Northern Hardwood Forest plot. These did not correspond with EPA Level IV Ecoregions (**Table A10**).

Coarse Woody Debris

Coarse woody debris (CWD) was present along transects in 22 plots (55%) and was 18 ± 9.5 cm (7.1 ± 3.8 in) in diameter and 6 ± 4.5 m (19.5 ± 14.7 ft) long on average. There were 29.6 pieces of CWD per ha (12 per ac) and average decay class was 2.5 ± 1.1 (1 = not decayed, 5 = very decayed). There were no statistically significant differences between core and edge plots for any CWD metrics (paired Wilcoxon signed-rank tests, $p > 0.05$) and no difference between presence or absence of CWD (chi-squared test, $p = 0.34$).

Ground Cover

Ground cover was 53.4 ± 17.2% leaf litter and soil, 33 ± 18.3% herbaceous vegetation, 6.9 ± 3.6% wood, and 6.7 ± 8.5% rock. These percentages were not significantly different between core and edge plots (paired t-tests, $p > 0.05$).

Sugaring Infrastructure

Taps and Tubes

Tap density was 171 ± 90 taps per ha (69 ± 36 taps per ac) and was not significantly different between core and edge plots (paired t-test, $p = 0.71$).

Minimum tube height was 1 ± 0.24 m (3.27 ± 0.78 ft) while tubing length was 1305 ± 640 m per ha (1,733 ± 849 ft per ac), with tube height and length not differing significantly between core and edge plots (paired t-test, p = 0.80 and 0.16, respectively). For each tube segment measured, maximum tube height was 0.30 ± 0.24 m (12.73 ± 10.5 in) higher than the minimum tube height.

Number of taps was correlated with tube length within each plot (Pearson's $r = 0.55$, $t(38) = 4.05$, $p < 0.001$) and tree species diversity decreased with increasing tubing length ($r = -0.53$, $t(38) = -3.82$, $p < 0.001$).

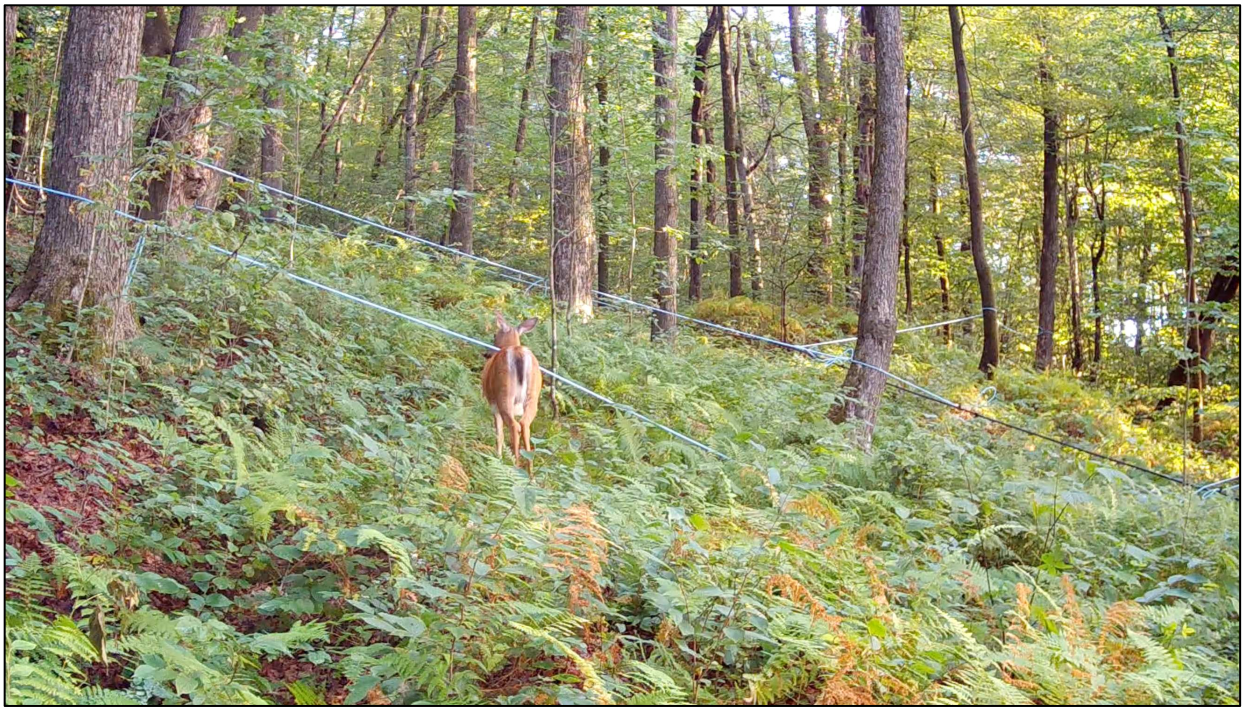

Figure 18. White-tailed deer browsing undeterred by the low sap line in Marlboro, Vermont.

Roads

Road length was 60 ± 57 m per ha (80 ± 76 ft per ac) and did not differ significantly between core and edge plots (paired t-test, $p = 0.20$), although road length was slightly higher in core plots.

Wildlife

Mammals

Large mammals in sugarbushes were primarily white-tailed deer, which were detected in 72.5% of plots (29 plots) at a rate of 0.17 detections per plot per day, followed by American black bear (40% of plots; 16 plots; 0.05 detections per plot per day), moose (10%; 4; 0.05), coyote (2.5%; 1; 0.03), and raccoon (5%; 2; 0.05). Bobcat and red fox (*Vulpes vulpes*) were also detected beyond the 30-day detection window. White-tailed deer and American black bear were detected slightly more often along the edge of the sugarbush (**Table 7**).

Medium-sized mammals were gray squirrel (*Sciurus carolinensis*), detected in 37.5% of plots (15 plots) at 0.20 detections per plot per day, fisher (10%; 4; 0.04), and North American porcupine (*Erethizon dorsatum*; 2.5%; 1; 0.50). North American porcupine was detected only in the core of the sugarbush (**Table 7**).

Small mammals were mouse spp. (*Peromyscus* spp.), detected in 25% of plots (10 plots) at 0.30 detections per plot per day, followed by flying squirrel spp. (*Glaucomys* spp.; 7.5%; 3; 0.16), red squirrel (*Sciurus vulgaris*; 10%; 4; 0.08), eastern chipmunk (*Tamias striatus*; 10%; 4; 0.05), and groundhog (*Marmota monax*; 2.5%; 1; 0.03). Long-tailed weasel (*Neogale frenata*) and shrew spp. were detected beyond the 30-day detection window.

Table 7. Mammal species detected at core and edge of 20 sugarbushes surveyed within a 30-day window using 8EHP5 Browning Elite HP5 trail cameras, with staggered deployment Jul 1 through Sep 9, 2025. Other species detected beyond the 30-day window were bobcat, red fox, long-tailed weasel, and shrew spp.

Species	Plot-days detected	Core	Edge	Δ	
North American porcupine	11	11	0	11	potential core-associated species
Flying squirrel spp.	14	12	2	10	
Gray squirrel	70	40	30	10	
Red squirrel	8	7	1	6	
Eastern chipmunk	6	5	1	4	
Raccoon	3	3	0	3	
Coyote	1	1	0	1	
Fisher	5	3	2	1	
Mouse spp.	49	25	24	1	
Groundhog	1	0	1	1	
Moose	5	2	3	-1	
American black bear	22	5	17	-12	
White-tailed deer	126	46	80	-34	potential edge-associated species

Table 8. Top 25 bird species detected at core and edge of 20 sugarbushes surveyed within a 5-day window using Song Meter Micro 2 audio device and BirdNet v2.4 species detection software. Audio was recorded for 10 minutes every half hour from 5AM to 9AM with staggered deployment Jul 1 through Sep 1, 2025.

Species	Plot-days detected	Core	Edge	Δ	
Hermit thrush*	96	56	40	16	potential core-associated species
Red-breasted nuthatch	61	37	24	13	
Winter wren	17	15	2	13	
Golden-crowned kinglet	24	17	7	10	
Scarlet tanager	32	20	12	8	
Brown creeper	24	16	8	8	
Black-capped chickadee	21	14	7	7	
Yellow-billed cuckoo	7	7	0	7	
Broad-winged hawk	9	7	2	5	
Wood thrush	76	40	36	4	
Hairy woodpecker	14	9	5	4	
Red-eyed vireo	8	6	2	4	
Ovenbird	51	27	24	3	
Black-throated green warbler	43	22	21	1	
Blue-headed vireo	8	4	4	0	
Blue jay	6	3	3	0	
Common raven	9	4	5	-1	
Great crested flycatcher	11	4	7	-3	
Downy woodpecker	11	3	8	-5	
Pileated woodpecker	12	3	9	-6	
Barred owl	33	12	21	-9	
Veery	20	5	15	-10	
White-breasted nuthatch	44	16	28	-12	
Eastern wood-pewee	41	14	27	-13	
Black-throated blue warbler*	40	10	30	-20	potential edge-associated species

* significant

Birds

Bird detections were most frequent for hermit thrush (*Catharus guttatus*; 77.5% of plots; 31 plots; 0.48 detections per plot per day), followed by wood thrush (62.5%; 25; 0.38), red-breasted nuthatch (*Sitta canadensis*; 57.5%; 23; 0.30), ovenbird (*Seiurus aurocapilla*; 55%; 22; 0.26), white-breasted nuthatch (*Sitta carolinensis*; 52.5%; n = 21; 0.22), and black-throated green warbler (42.5%; 17; 0.22; **Table 8**).

From the subset of audio that I examined (200 plot-days at 7:00AM from 34 plots), all broad-winged hawk (*Buteo platypterus*) and barred owl (*Strix varia*) detections were false-positives. Broad-winged hawk detections were often eastern wood-pewee (*Contopus virens*) or white-throated sparrow (*Zonotrichia albicollis*), while barred owl was often the howl of wind. Common false-negatives were red-eyed vireo (*Vireo olivaceus*; incorrectly excluded from 9% of days examined), black-capped chickadee (*Poecile atricapillus*) and blue jay (*Cyanocitta cristata*; 5.5% each), American robin (*Turdus migratorius*; 3%), hermit thrush, ovenbird, scarlet tanager, white-breasted nuthatch, and white-throated sparrow (2.5% each), American crow (*Corvus brachyrhynchos*), American redstart, eastern wood-pewee, red-breasted nuthatch and veery (2% each).

Habitat, Sugaring Infrastructure, and Wildlife

For mammal and bird detections, only hermit thrush detections were signifi-cantly greater in core plots, while black-throated blue warbler detections were greater at edge plots (Wilcoxon signed-rank tests, *p* = 0.029 with power = 0.56 and *p* = 0.033 with power = 0.62, respectively).

Mammal detections were not signifi-cantly correlated with tap density, tubing length, or road density, with the ex-ception of eastern chipmunk, which showed fewer detections with increasing tubing length (Spearman, *rho* = -0.347, *p* = 0.035, power = 0.57). Eastern chipmunk detections also increased with increasing tree species diversity (*rho* = 0.387, *p* = 0.018, power = 0.67).

For birds, species richness decreased with increasing road density (*rho* = -0.353, *p* = 0.026, power = 0.62), while winter wren and ovenbird decreased with increasing tubing length (*rho* = -0.373, *p* = 0.018, power = 0.67; *rho* = -0.316, *p* = 0.047, power = 0.52). In contrast, eastern wood-pewee increased with increasing tap density (*rho* = 0.366, *p* = 0.020, power = 0.66), and downy woodpecker increased with increasing tubing length (*rho* = 0.360, *p* = 0.023, power = 0.64). Bird species richness also increased with sapling-poletimber basal area (*rho* = 0.389, *p* = 0.013, power = 0.71), tree species diversity (*rho* = 0.337, *p* = 0.031, power = 0.59), and structural diversity (*rho* = 0.315, *p* = 0.048, power = 0.52).

Discussion

Wildlife habitat found in the assessed sugarbushes was characterized by mid-successional, sugar maple-dominated stands, the forest floor mostly leaf litter interspersed with herbaceous cover, and coarse woody debris and slash piles were limited and small in size. Active streams and pooling water were also scarce, likely due to the persistent drought during the survey period. Saplings of American beech were twice as common as sugar maple, and sapling mortality was high from shading out by larger trees, though live and dead trees over 60 cm (23.6 in) DBH were infrequent. White-tailed deer, American black bear, and black-throated blue warbler were found along the edge of these sugarbushes, while North American porcupine, flying squirrels, and hermit thrush were more common at the core. Of these core-edge associations, only the black-throated blue warbler and hermit thrush were significant.

Overall, the forest diversity was moderate, and sugar maple did not exceed 75% of basal area (the minimum diversity required by UVA for an entire stand), though sugar maple basal area was over 90% for nearly a quarter of plots. Where tree species were diverse, forest structure was also diverse, perhaps reflecting a natural variation within sugar maple-dominated Northern Hardwood Forests, as well as differences in management where some sugarmakers maintain more diverse forests than others. The variability in natural community types within sugarbushes further indicates that sugarmakers do not operate within ecologically uniform stands, and that small-scale variation in soils, topography, and microhabitat within a single sugarbush may support a diversity of wildlife associated with different natural community types found throughout a sugarmaker's forest.

Despite this potential for variability, the dominance of mid-sized trees found in this assessment suggests a limited availability of early-successional and mature forest habitat that many wildlife species require. Although saplings were present in the sample plots, they exhibited high mortality and occurred beneath closed canopies in high basal area stands, indicating suppressed regeneration rather than early succession driven by gaps in the forest canopy. These early-successional habitats are important because they are preferred or utilized by 77% of the Northern Hardwood Forest wildlife (DeGraaf et al. 2006). Stands with large, mature trees are also important for wildlife, with 80% of the Northern Hardwood Forest wildlife species listed by DeGraaf et al. (2006) preferring or utilizing large trees for the forage and shelter opportunities provided by increased coarse woody debris, loose bark, and tree cavities. As trees age, they develop cracks, loose bark, and small holes that support wildlife such as woodpeckers, owls, bats, and flying squirrels, while large hollow trees are used by porcupines, gray foxes, fisher, raccoon, Virginia opossum, and American black bear (Bütler et al. 2024; DeGraaf et al. 2006). In this assessment, however, large trees were limited and only two dead trees over 60.96 cm (24 in) DBH (large sawtimber) were measured.

The mammals and birds detected represented typical Northern Hardwood Forest wildlife species associated with a range of forest conditions, including mixed-age stands, mature forest, and structurally diverse habitat features (DeGraaf et al. 2006). Commonly detected mammal species such as eastern gray squirrel, eastern chipmunk, white-tailed deer, and American black bear are associated with a broad range of forest conditions from sapling-aged forests to large sawtimber, as well as habitat features including mast-producing trees, understory cover, wetlands, and down logs. Other mammals detected, such as fisher, North American porcupine, and flying squirrels, are more strongly associated with older-aged forest conditions and structural features including mature trees, cavity structures, hollow logs, and den trees. Similarly, commonly detected bird species such as eastern wood-pewee, winter wren, hermit thrush, and golden-crowned kinglet are associated with a broad range of forest conditions including forest edges, dense understory vegetation, uneven-aged stands, and coniferous-deciduous forests. Other bird species detected, including wood thrush, ovenbird, scarlet tanager, pileated woodpecker, brown creeper, barred owl, and several woodpecker species, are more strongly associated with mature forest conditions and structurally complex habitat features such as large trees, uneven-aged forest structure, loose bark, cavity trees, and standing dead trees with decaying wood or hollow interiors (DeGraaf et al. 2006).

When evaluating relationships between wildlife detections and habitat or sugaring infrastructure, no plot-level characteristics were significantly different between core and edge plots, including sugaring infrastructure (taps, tubes, and roads), forest characteristics (tree species composition, tree size classes, coarse woody debris, and ground cover), and topography (slope and elevation). This suggests that differences in these variables were greater from one sugarbush to the next rather than between the core and the edge of these sugarbushes. While detections of some species showed significant increase or decrease with sugaring infrastructure and habitat variables, these relationships were not consistent. For example, eastern chipmunk detections declined with increasing tubing length and increased with tree species diversity. Winter wren and ovenbird detections also declined with increasing tubing length. Overall, bird species richness declined with increasing road density but increased with sapling-poletimber basal area, tree species diversity, and structural diversity. Alternatively, some species were detected more with increased sugaring infrastructure. Downy woodpecker detections increased with tubing length and eastern wood-pewee increased as tap density increased, though these relationships likely have more to do with indirect forest characteristics of a site with more or fewer taps rather than the influence of the taps themselves. These contrasting responses indicate that sugaring infrastructure may not have a uniform impact, but impact each species differently, similar to findings from Morse (2025).

Statistical power for the tests with significant results ($p < 0.05$) was moderate (power = 0.52-0.71), indicating the current sample size (20 sites, 20 paired plots, 40 total plots) was generally low-to-adequate to detect relationships between mammal and bird detections and site characteristics. Because bird species were detected more often, relationships between birds and sugaring infrastructure variables provide a useful framework for detecting patterns within these systems. Mammals, on the other hand, were detected less frequently and some relationships, such as moose detections and core *vs* edge require over 130 paired plots, and mammal species richness vs tree species diversity require over 150 to reach adequate statistical power (0.80).

While the results suggest that the cumulative impact of tubing did not impose a clear barrier to wildlife movement, detections of moose were limited within the surveyed sugarbushes and more research is needed to determine the direct impact of tubing on movement moose. Results from this assessment show that tubing averaged 1 m (3.27 ft) in height, substantially lower than the shoulder height of an adult bull moose (1.8 m; 6 ft; New York State Department of Environmental Conservation 2006), and may make navigating under these tubes more difficult under conditions of deep snow. Video observations of all other wildlife species, however, did not indicate impediment from tubing as they moved through the forest. Thus, forest management that maintains a forest of high structural and species diversity, with frequent large standing dead trees, coarse woody debris and slash piles, and areas of pooling water may play a greater role in shaping the suitability of sugarbushes for wildlife than the presence of tubing.

Figure 19. American black bear examines fallen limbs in in Chittenden, Vermont.

Recommendations for Forest Management and Future Research

Sugarbushes in Vermont, as indicated by these geospatial and field assessments, operate within the state's most intact and connected forest systems, across natural communities that are naturally dominated by sugar maples. Stand-level habitat was moderately diverse in structure and species tree composition, with limited availability of key features such as coarse woody debris, which was often small and scarce, large standing dead cavity trees, and wet areas. Because these working lands have remained forested as they have, the focus can shift beyond keeping these forests as forest – an essential baseline for Northern Hardwood Forest wildlife – to considering how to best manage sugarbush stands to maximize habitat quality and movement potential for Vermont's wildlife.

Bobcat emerged as a primary focal species from the geospatial assessment because modeled movement areas overlapped substantially with Vermont sugarbushes, suggesting that sugarbushes may provide important movement opportunities for bobcats. However, bobcat was uncommon and only detected outside of the 30-day window of the field assessment. Given the preference of bobcat for areas of shrub, wetlands, and forest while avoiding areas with higher road density (Donovan 2011), management within sugarbushes could include maintaining small forest openings that promote dense regeneration and shrub layers, particularly near wet areas and forest edges, to improve suitable bobcat habitat within sugarbushes.

Similarly, fisher may serve as an additional focal species in sugarbushes, preferring unfragmented interior forest habitat that features uneven-aged stands as well as old forests with large snags and fallen trees (DeGraaf et al. 2006). Although fisher movement was not evaluated in the geospatial assessment, studies have shown that fisher core use areas are associated with dense canopy cover, mature conifer forest, and reduced human disturbance (Kordosky et al. 2021). Managing for the fisher's preference for mixed-forest composition also means cultivating coniferous stands, adding to the diversity of tree species throughout the sugarbush.

Although these recommendations are specific to bobcat and fisher, management that supports these conditions mirrors those suggested by the Bird-friendly Maple program (Vermont Organic Farmers and Audubon Vermont 2025) and provides an umbrella approach that supports habitat requirements for a wide range of wildlife species (DeGraaf et al. 2006). These management strategies are most effective when neighboring landowners coordinate to identify movement chokepoints and maintain forested blocks with dense understory cover where wildlife movement is highest. Additionally, landowners can work together to protect vernal pools, seeps, streams, and other wetland types in their many various forms. Although often infrequent in distribution, these wetlands contribute disproportionately to ecological function and biodiversity (Calhoun and deMaynadier 2007; Meyer et al. 2007).

Figure 20. Forest road through a sugarbush in Underhill, Vermont

From the observations of video footage captured throughout the field assessment, wildlife responses across the sampled sugarbushes suggest that forest management decisions might be more impactful to wildlife than sugaring infrastructure, with the exception of moose. Moose moving through sugarbushes may be impeded by tubing and more direct research is needed to understand how these larger animals navigate larger-scale sugaring operations, particularly during late winter and early spring when energetic constraints are greatest (Schwartz et al. 1988), habitat use becomes more restricted across the landscape (Blouin et al. 2021), and snow depth further reduces clearance beneath tubing. For sugarmakers, care may be taken to set mainline tubes higher than 1.8 m (6 ft) when possible, particularly throughout areas of known moose corridors within sugarbushes at 300-600 m (1,000 - 2,000 ft) elevation in mixed deciduous-coniferous forests where moose are more common (Millette et al. 2014; **Figure 21**).

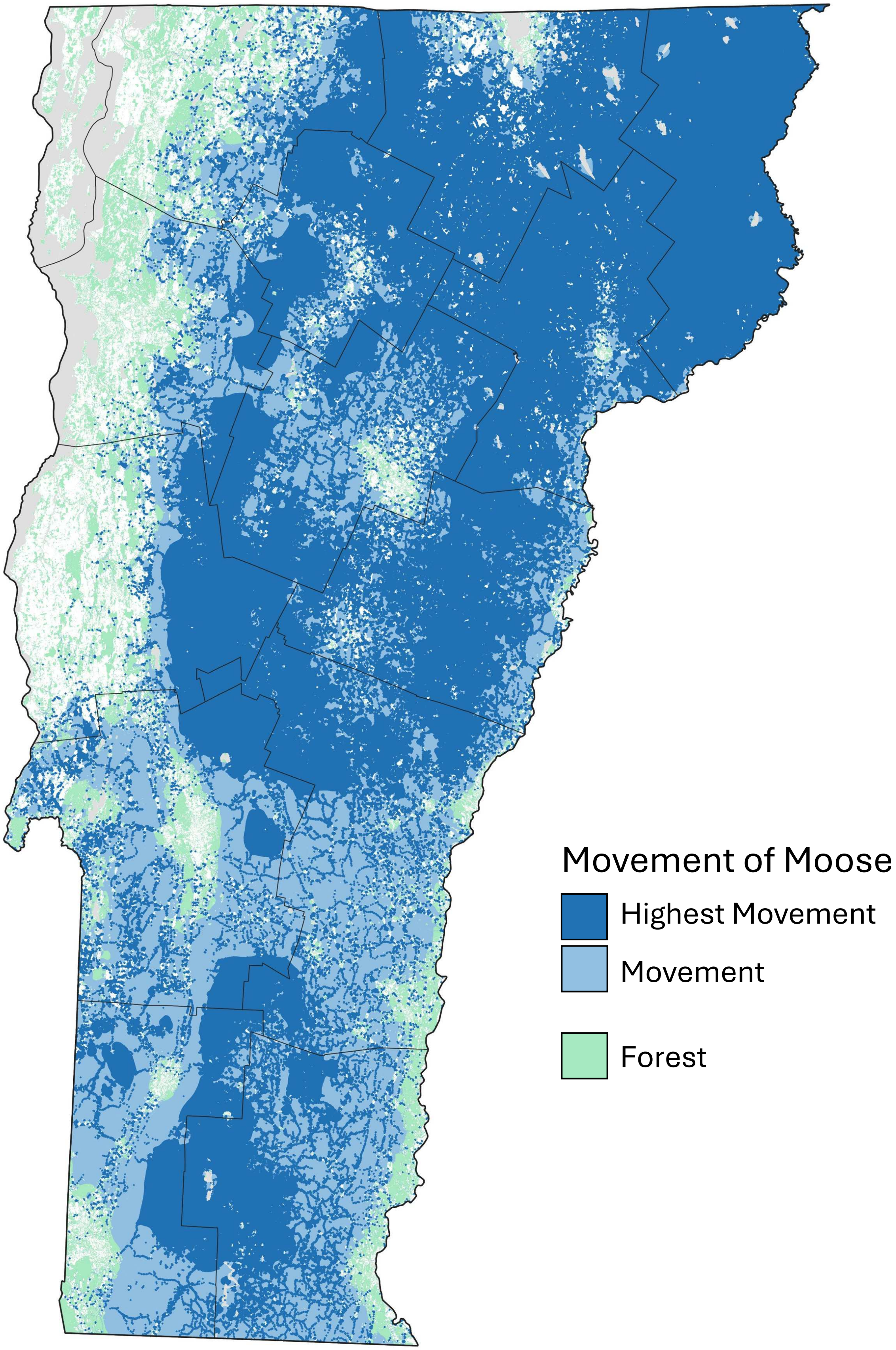

Figure 21. Areas of moose movement across Vermont developed from models provided by Drasher et al. (2025).

From this work, opportunities emerge to manage sugarbushes to maximize habitat for wildlife. This includes management that leaves large coarse woody debris, large slash piles, large standing dead trees, and wet areas such as streams, seeps, and vernal pools, while maintaining a diversity of tree species and sizes. Because wildlife use was present throughout sugarbushes and not consistently related to sugaring infrastructure, management of forest structure, species composition, and these special habitat features and may be a more important factor than the presence of taps or tubing.

While this experimental design provided a characterization of conditions at the core and edge of sugarbushes and an opportunity to observe wildlife interactions with sap lines, the design did not allow for strongly contrasting conditions from one plot to the next, making relationships between wildlife and plot-level variables difficult to isolate. More targeted study designs that explore clear categorical differences, along with increased sample sizes would help clarify relationships between habitat, infrastructure, and wildlife use that were not consistently detected in this assessment.

Future research using contrasting sites should explore the utility of a special habitat feature more directly, the influence of human activity on wildlife within sugarbushes, or sugaring intensity as measured by the presence or density of taps or tubing. Future research should also focus on species-specific responses to sugaring, particularly for moose where tubing may influence movement, and bobcat and fisher which may both serve as potential sugarbush focal species. The maps provided here may also be used to select study sites within high value ecological areas to explore potential impacts of sugaring on wildlife within these critical areas where ecological integrity is most important across Vermont.

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All photos in this report are from the field assessment
and should be attributed to Matthias Sirch.

Appendix

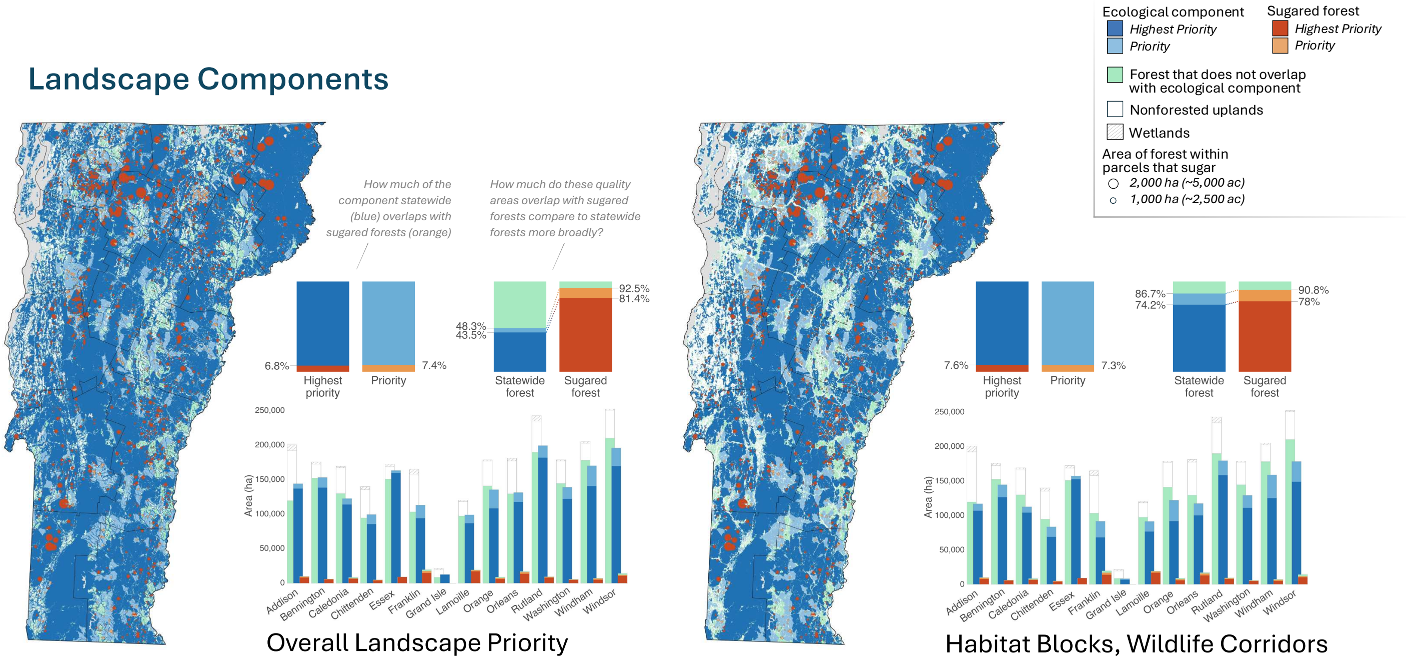
Table A1. Landscape-level components of the Vermont Conservation Design.

Landscape components	Description
Overall Landscape Priority Layer: Bio4_LandscapeComponents Field: OverallPriority	Combined ranking of all landscape-scale components
Habitat Blocks, Wildlife Corridors Layer: Bio4_HabitatBlocks Field: Overall_Priority	Large (>60.7 ha; >150 ac), contiguous, unfragmented natural areas bounded by roads that support wildlife habitat and movement
Interior Forest Layer: Bio4_LandscapeComponents Field: InteriorForestPriority	Large unfragmented forests with ≥101.2 ha (≥250 ac) core forest and forest edge along roads removed
Forest Connectivity Layer: Bio4_LandscapeComponents Field: ConnectivityBlocksPriority	Forest blocks that enable movement of wildlife across the landscape, including lower quality habitats that connect larger forest blocks
Geologic Diversity Layer: Bio4_LandscapeComponents Field: GeologicPriority	Representative composition of Vermont's physical features (bedrock, soils, landforms)
Surface Water and Riparian Connectivity Layer: Bio4_LandscapeComponents Fields: SurfaceWaterPriority, RiparianConnectivity	Critical networks of rivers, ponds, wetlands, etc, and the terrestrial corridors that connect them

Table A2. Species-level components of the Vermont Conservation Design.

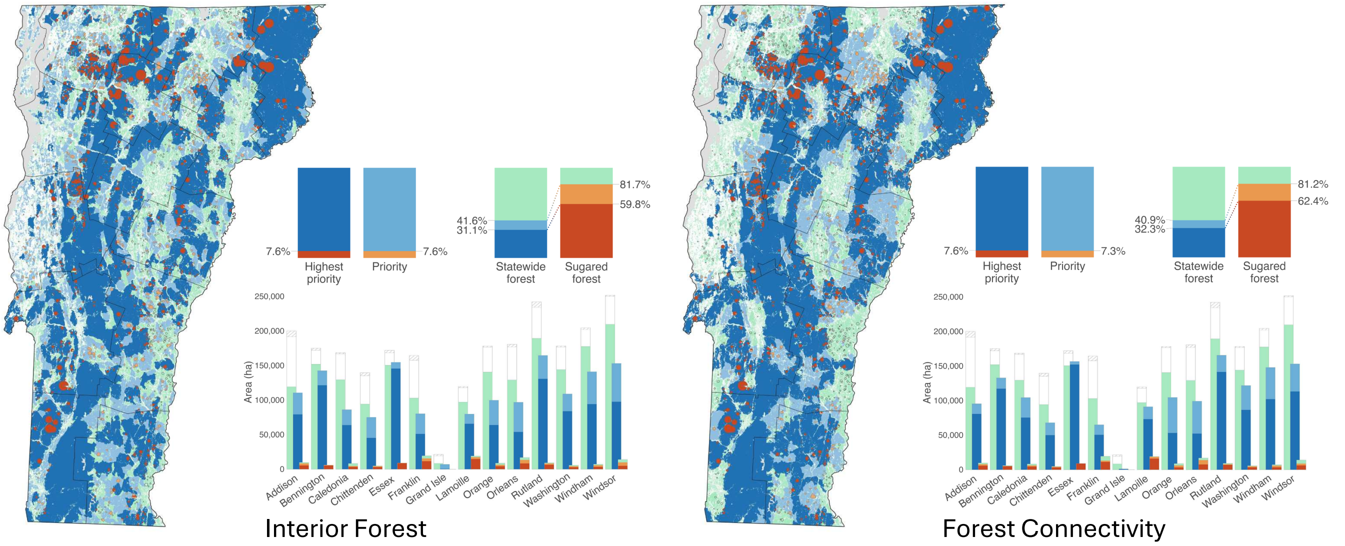
Species components	Description
Overall Species Priority Layer: Bio4_SpeciesComponents Field: OverallPriority	Combined ranking of all species-level components
Natural Communities Layer: Bio4_SpeciesComponents Field: NaturalCommunities	Representative composition of high-quality examples of all natural communities
Rare, Threatened, Endangered Species, and Uncommon Plants and Animals Layer: Bio4_SpeciesComponents Fields: RTE; UncommonSpecies	Locations of rare or sensitive plant or animal species that require conservation action
Wildlife Road Crossings Layer: Bio4_SpeciesComponents Field: WildlifeRoadCrossings	Road segments with surrounding high quality habitat buffered by 150 m (492 ft), where wildlife road crossings are most likely
Vernal Pools Layer: Bio4_SpeciesComponents Field: VernalPools	Seasonal wetlands essential for amphibian breeding and specialized species.
Aquatic Habitat Layer: Bio4_SpeciesComponents Field: AquaticHabitats	Essential surface water networks with high biodiversity, including mountain headwaters

Landscape Components



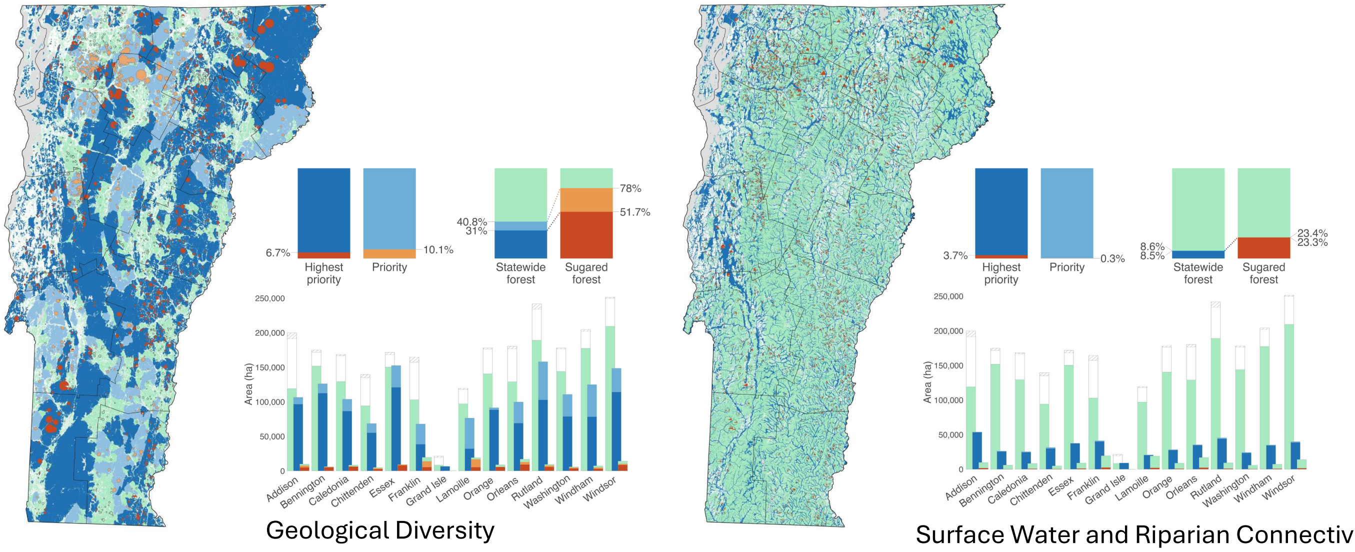
Overall Landscape Priority

Habitat Blocks, Wildlife Corridors



Interior Forest

Forest Connectivity



Geological Diversity

Surface Water and Riparian Connectivity

Figure A1. High value landscape component areas from the Vermont Conservation Design (blue) and where these areas overlap with forest of parcels that indicated sugaring (orange), highlighting where ecological sugarbush management is particularly important. Area of water are not included in these proportions.

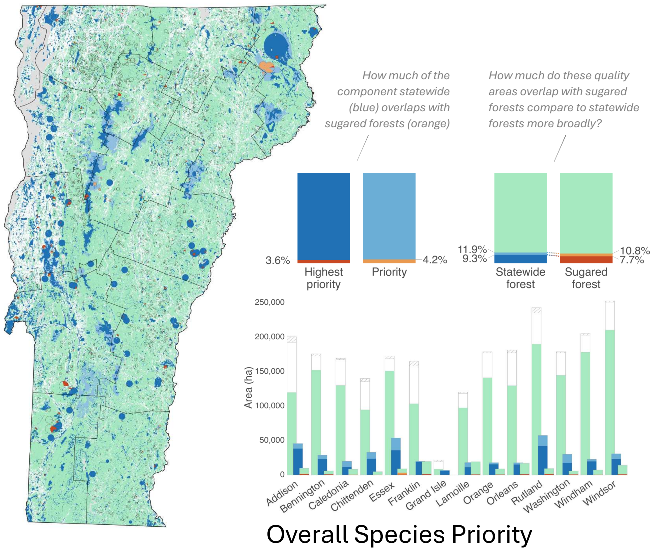
Ecological component
🟦 *Highest Priority*
🟦 *Priority*

Sugared forest
🟥 *Highest Priority*
🟧 *Priority*

🟩 Forest that does not overlap with ecological component
☐ Nonforested uplands
▨ Wetlands

Area of forest within parcels that sugar
○ *2,000 ha (~5,000 ac)*
○ *1,000 ha (~2,500 ac)*

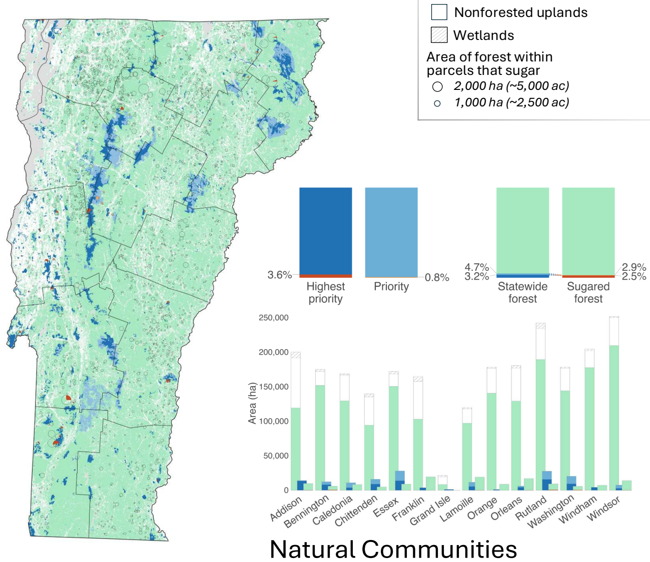
Species Components



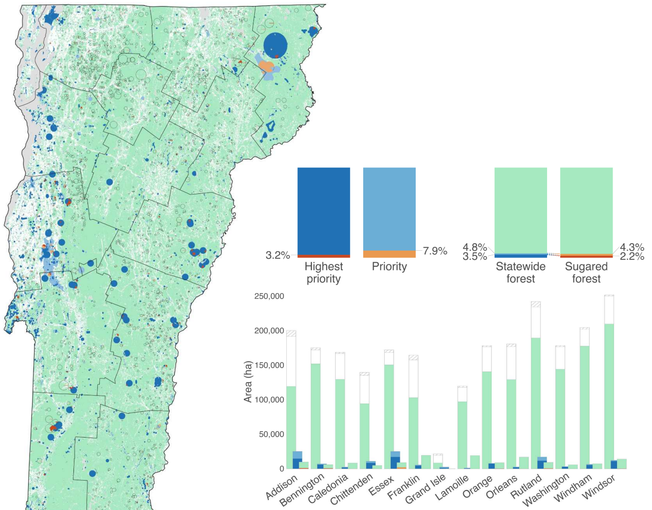
How much of the component statewide (blue) overlaps with sugared forests (orange)

How much do these quality areas overlap with sugared forests compare to statewide forests more broadly?

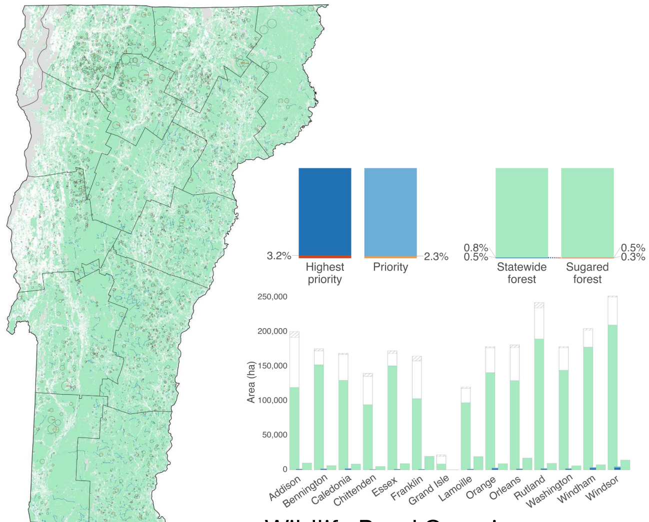
Overall Species Priority



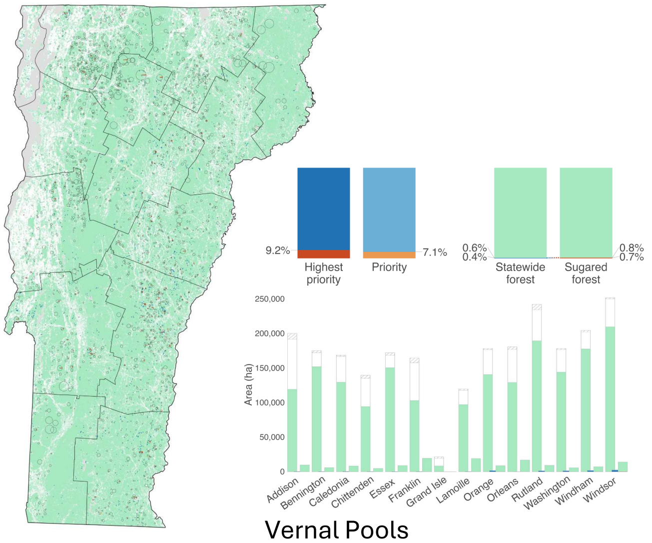
Natural Communities



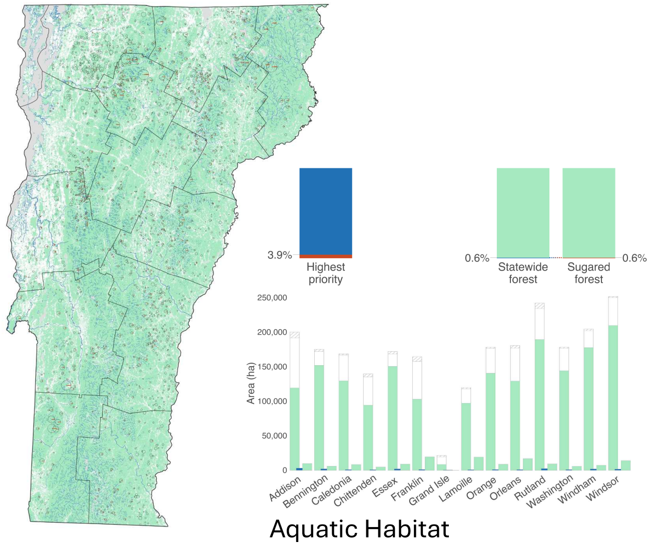
Rare, Threatened, Endangered, and Uncommon Plants and Animals



Wildlife Road Crossings



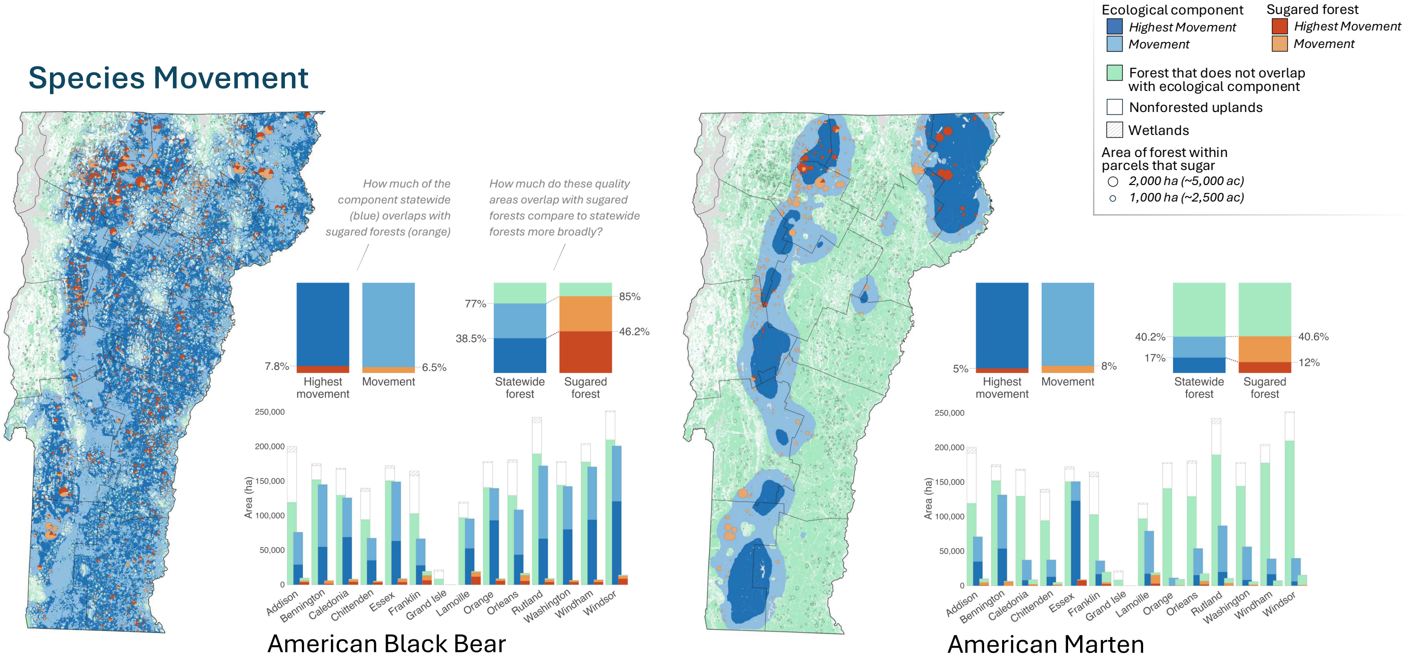
Vernal Pools



Aquatic Habitat

Figure A2. High value landscape component areas from the Vermont Conservation Design (blue) and where these areas overlap with forest of parcels that indicated sugaring (orange). Area of water are not included in these proportions.

Species Movement

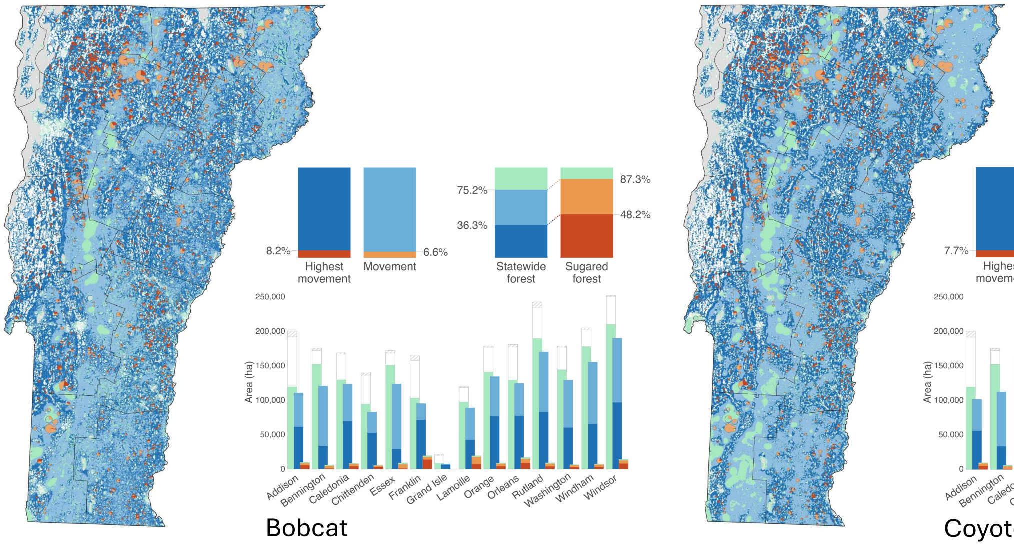


American Black Bear

Ursus americanus

American Marten

Martes americana STATE ENDANGERED (S1)

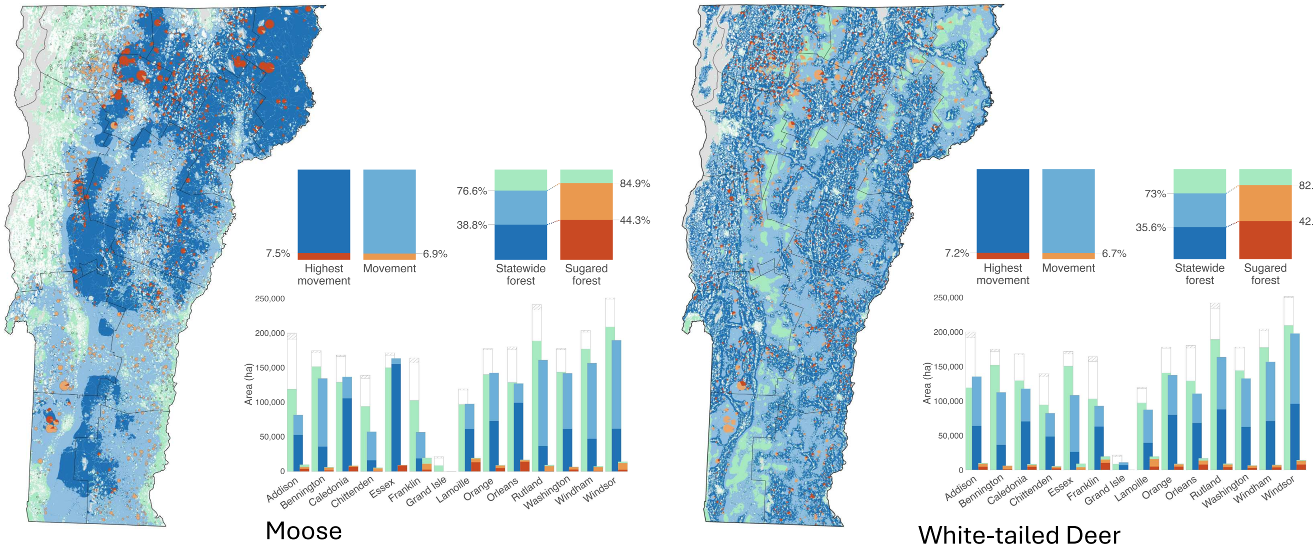


Bobcat

Lynx rufus

Coyote

Canis latrans



Moose

Alces alces

White-tailed Deer

Odocoileus virginianus

Figure A3. High value wildlife movement areas from models provided by Drasher et al. (2025; blue) as they intersect with forests of parcels that indicated sugaring (orange). Area of water are not included in these proportions.

Table A3. Percent of sugarbushes overlapping any portion of the component.

Component	Category	Priority (%)	Highest Priority (%)	Either (%)
Bobcat	Species Movement	98.9	98.5	99.8
Coyote	Species Movement	98.0	97.6	99.7
White-tailed deer	Species Movement	98.9	96.8	99.5
Overall landscape components	VCD Landscape Component	40.8	96.4	98.5
Moose	Species Movement	93.7	76.0	94.8
American black bear	Species Movement	93.6	88.7	94.4
Habitat blocks, wildlife corridors	VCD Landscape Component	24.3	73.0	90.1
Surface water and riparian habitat	VCD Landscape Component	24.0	89.9	89.9
Overall species components	VCD Species Component	30.9	75.0	80.2
Interior forest	VCD Landscape Component	35.2	47.0	77.4
Forest connectivity	VCD Landscape Component	31.5	48.6	74.4
Geological diversity	VCD Landscape Component	23.5	51.9	73.0
Aquatic habitat	VCD Species Component	0	32.0	32.0
Wildlife road crossings	VCD Species Component	14.5	17.8	27.2
American marten	Species Movement	22.6	4.5	25.0
Rare, threatened, endangered, and uncommon species	VCD Species Component	8.7	12.7	17.3
Natural communities	VCD Species Component	2.3	9.0	10.4
Vernal pools	VCD Species Component	2.6	7.6	9.9

Table A4. Land type from LANDFIRE Existing Vegetation Type (EVT) within parcels that indicated sugaring.

Land type	Climate	Percent (%)
Northern Hardwood Forest	Laurentian-Acadian	51.4
Pasture and Hayland	Eastern Cool Temperate	11.9
Pine-Hemlock-Hardwood Forest	Laurentian-Acadian	4.8
Pine-Hemlock Forest	Laurentian-Acadian	4.5
Spruce-Fir Forest	Acadian-Appalachian Montane	4.1
Spruce-Fir-Hardwood Forest	Acadian Low-Elevation	4.0
Spruce-Fir Forest	Acadian Low-Elevation	3.5
Hardwood Forest	Laurentian-Acadian	2.4
Hardwood Forest	Acadian Low-Elevation	1.6
Row Crop	Eastern Cool Temperate	1.6
other		10.3

Table A5. Stand type where sugarbush management is listed as forest management (n = 2,989) within Use Value Appraisal parcels that indicated sugaring.

Stand type	Percent (%)
Sugar maple	40.2
Beech, birch, sugar maple	36.6
Mixed (25-65% softwood)	12.8
Beech, red maple	1.9
Hemlock	1.0
Pioneer species	0.8
White pine, red oak	0.6
Spruce	0.1
Aspen and/or white birch	0.1
other	4.5
not listed	1.4

Table A6. Additional forest management listed in stands with sugarbush management within Use Value Appraisal parcels that indicate sugaring where stand data were available (n = 2,989).

Forest management	Percent (%)
Crop tree release	4.4
Single tree selection (uneven-age management)	3.7
Invasive species control	3.3
Intermediate thinning (even-age management)	3.2
Group selection (uneven-age management)	1.8
Non-commercial forest stand improvement	1.4
Shelterwood cut (even-age management)	0.9
Salvage cut (uneven-age management)	0.2
Overstory removal cut (even-aged management)	0.1
Clearcut (even-aged management)	0.1
Species conversion	0.03
other	10.3
no other management listed	66.1

Table A7. Firewood removal by tree species of Use Value Appraisal parcels that indicate sugaring where Forest Management Activity Report data were available (n = 869).

Tree species	Percent (%)	Description
Deciduous		
Ash	35.0	Ash spp. (31.5%), white ash (3.4), black ash (0.1)
Maple	27.0	Maple spp. (14), red maple (7.2), sugar maple (5.8)
Birch	16.9	Birch spp. (8.9), yellow birch (4.1), white birch (2), paper birch (1), black birch (0.9)
American beech	10.8	
Cherry	3.4	
Oak	2.3	Oak spp. (1.6), northern red oak (0.6)
Poplar/aspen	1.6	Poplar spp. (1.3), aspen (0.3), quaking aspen (0.1)
Elm	0.6	
Hickory	0.4	
Eastern hophornbeam	0.4	
Ironwood	0.3	
Hawthorn	0.1	
Unspecified	5.3	
Conifer		
Pine	1.5	Pine spp. (1.1), eastern white pine (0.4)
Eastern hemlock	1.3	
Spruce	0.9	Spruce spp. (0.8), Norway spruce (0.1)
Balsam fir	0.4	
Tamarack	0.3	
Unspecified	0.3	
Mixed (25-65% softwood)	1.1	
Firewood not listed	59.3	

Table A8. Geology within forests of parcels that indicated sugaring.

a)

Bedrock geology	Percent (%)
Phyllite	32.5
Muscovite-schist	15.2
Quartzite	11.5
Quartz-feldspar-schist	7.0
Slate	3.4
Granofels	3.3
other	27.1

b)

Surficial geology	Percent (%)
Glacial deposit: till	85.3
Bedrock exposure	6.6
Glaciofluvial deposit: kame terrace	1.1
Glacial deposit: moraine	1.0
Glaciolacustrine deposit: silt and clay	1.0
Pluvial deposit: peat and/or muck	0.9
other	4.1

Table A9. Soil characteristics within forests of UVA parcels that indicated sugaring.

a)

Soil component names	Percent (%)
Tunbridge	20.3
Lyman	8.6
Vershire	7.7
Berkshire	7.4
Cabot	6.9
other	49.1

b)

Soil runoff potential	Percent (%)
Very high	35.7
High	47.8
Medium	5.7
Low	6.1
Very low	4.1
Negligible	0.6

c)

Soil drainage class	Percent (%)
Excessively drained	1.4
Somewhat excessively drained	20.8
Well drained	52.1
Moderately well drained	13.5
Somewhat poorly drained	2.3
Poorly drained	8.4
Very poorly drained	1.5

d)

Soil composition	Percent (%)
Sand	51.1 ± 16.1
Silt	42.3 ± 15.1
Clay	6.6 ± 5.8

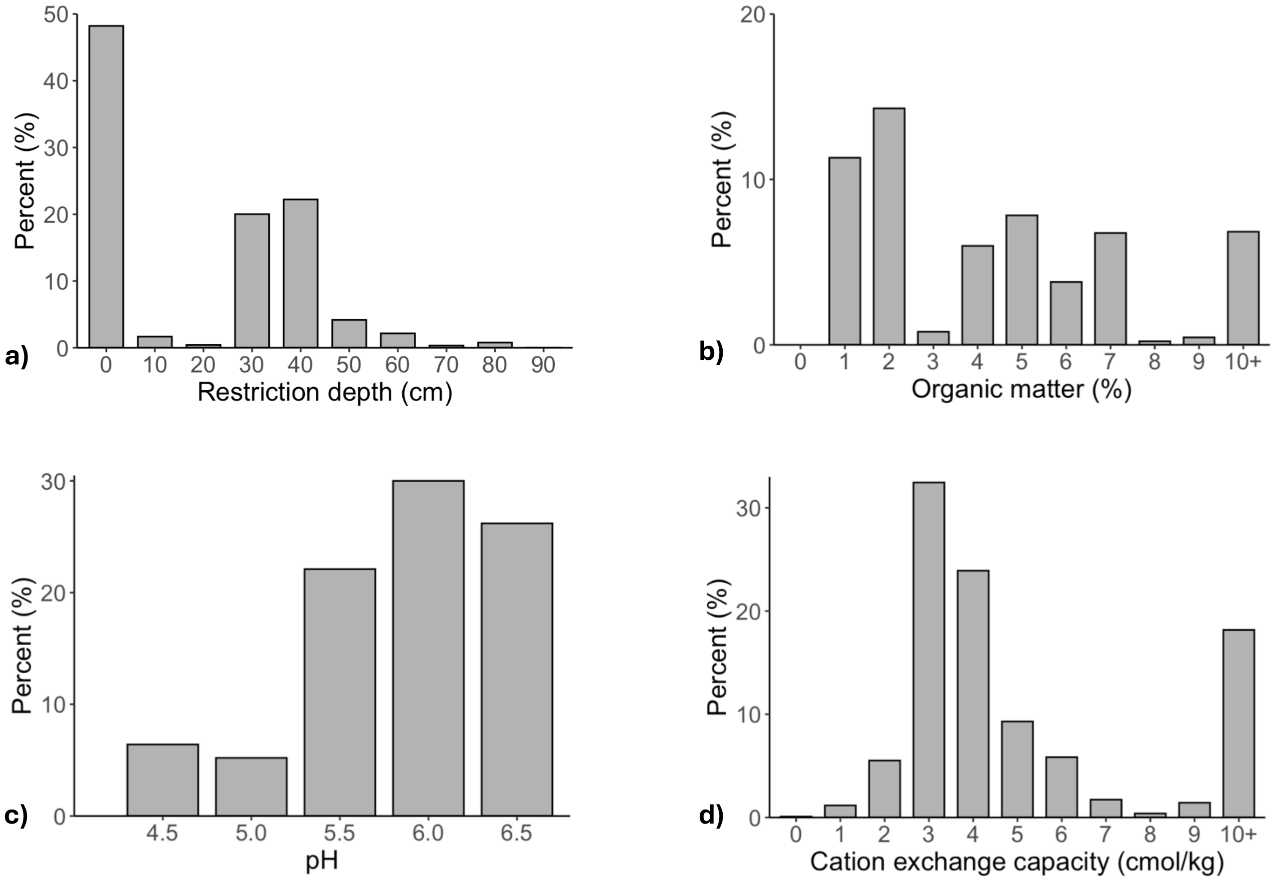


Figure A4. Soil characteristics within forests of UVA parcels that indicated sugaring.

Table A10. Ecoregion and natural community for core and edge plots from 20 surveyed sugarbushes across Vermont.

Plot	Natural community	EPA level IV ecoregion	Plot count
Core	Northern Hardwood Forest	Green Mountains/Berkshire Highlands	7
Core	Rich Northern Hardwood Forest	Green Mountains/Berkshire Highlands	2
Core	Northern Hardwood Forest	Green Mountain Foothills	2
Core	Northern Hardwood Forest	Quebec/New England Boundary Mountains	2
Core	Northern Hardwood Forest	Vermont Piedmont	2
Core	Northern Hardwood Forest	Western New England Marble Valleys	2
Core	Northern Hardwood Talus Woodland	Green Mountains/Berkshire Highlands	1
Core	Northern Hardwood Forest	Northern Piedmont	1
Core	Red Spruce-Northern Hardwood Forest	Northern Piedmont	1
Edge	Northern Hardwood Forest	Green Mountains/Berkshire Highlands	8
Edge	Northern Hardwood Forest	Northern Piedmont	2
Edge	Northern Hardwood Forest	Vermont Piedmont	2
Edge	Northern Hardwood Forest	Western New England Marble Valleys	2
Edge	Northern Hardwood Forest	Green Mountain Foothills	1
Edge	Northern Hardwood Talus Woodland	Green Mountain Foothills	1
Edge	Hemlock Forest	Green Mountains/Berkshire Highlands	1
Edge	Rich Northern Hardwood Forest	Green Mountains/Berkshire Highlands	1
Edge	Northern Hardwood Forest	Quebec/New England Boundary Mountains	1
Edge	Northern Hardwood Talus Woodland	Quebec/New England Boundary Mountains	1
		Total	40

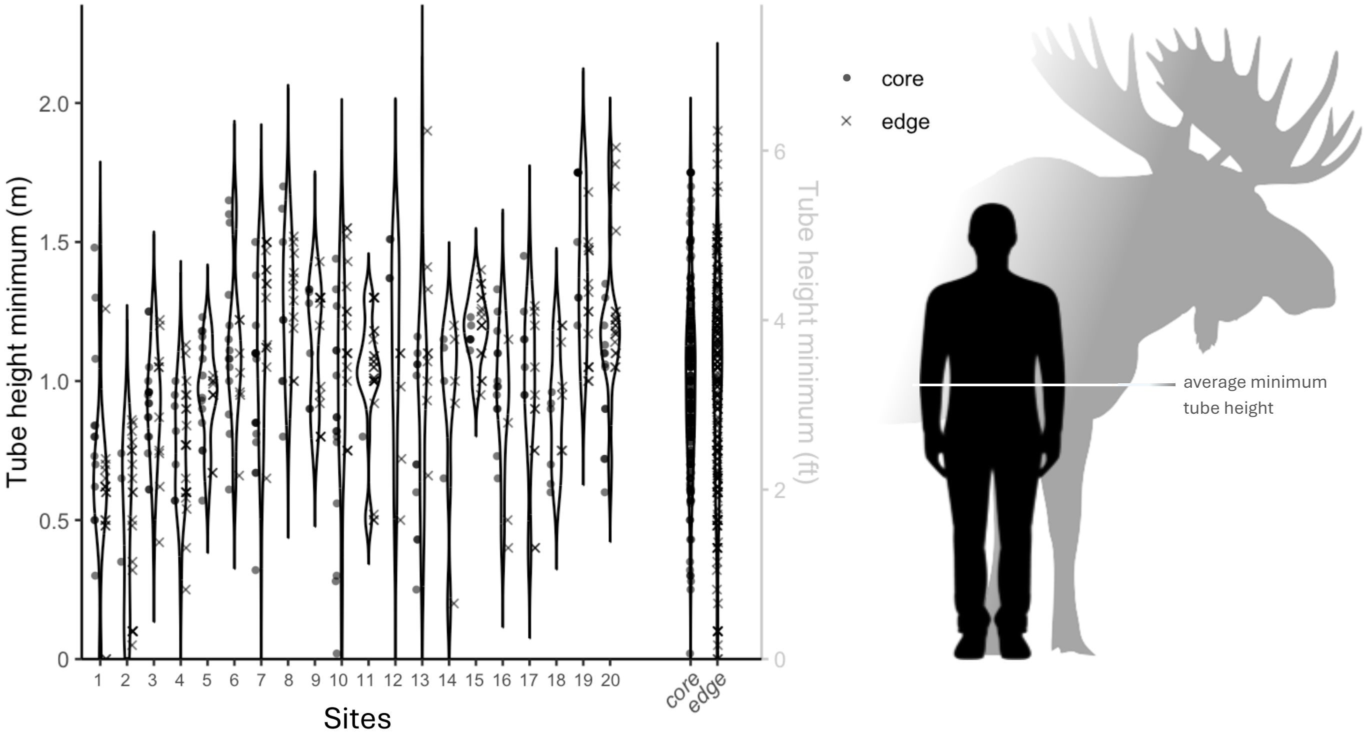


Figure A5. Minimum tube height for each tube segment across core and edge plots for each site, ordered from southern-most (1) to northern-most sites (20). Moose is shown as 1.8 m (6 ft) at the shoulder, human is 1.7 m (5.5 ft), and white line is average minimum tube height.

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