Reducing Wildlife Mortality on Roads in Vermont: Documenting Wildlife Movement near Bridges and Culverts to Improve Related Conservation Investments

September 30, 2016

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Acknowledgements

This project would not have been possible without the contributions of the following individuals:

- James Brady, Vermont Agency of Transportation
- Gina Campoli, Vermont Agency of Transportation
- Laura Farrell, Phd.
- Melissa Gaydos, National Wildlife Federation
- Chris Hilke, National Wildlife Federation
- Jens Hilke, Vermont Department of Fish and Wildlife
- Alan Howard, University of Vermont
- Glenn McRae, University of Vermont Transportation Research Center
- Allan Thompson, Northern Stewards LC

Funding for the project was through the Vermont Agency of Transportation (by way of the University of Vermont Transportation Research Center) and from a grant from the DeCoizart Foundation by way of the National Wildlife Federation

Executive Summary

This project gathered and analyzed game-camera data on the frequency of under-highway wildlife movement through bridges and culverts in Vermont. Our analytical objective was to generate results-based recommendations for improving the permeability of highways in Vermont to increase the frequency of under-road movement of wide-raging terrestrial species. Specifically, this project assessed and then modified an analytical framework developed in the western United States that characterizes 1) the usability of a given structure for wildlife through-passage; and 2) relationships between species use and transportation structure size for applicability in Vermont. 573 through-passages of a set of 13 focal species were recorded at 23 culverts and bridges on busy road corridors. Results indicate that a modified framework that relates potential species use to culvert/bridge size is useful for identifying the potential benefit of projects to increase transportation structure usability for wildlife, provided that a given structure and habitat in its vicinity are suitable for wildlife. Variation in through-passage data among sites suggested the importance of site and structural characteristics in determining the frequency of use of a given bridge or culvert, specifically identifying local-scale structural connectivity, the presence of nearby deterring factors such as pens of hunting dogs, and the availability of dry even movement surfaces inside of a structure as important. Also, we estimate that only a small minority of transportation structures on the highway system in Vermont are currently usable by wider-ranging wildlife, and that existing culverts and bridges ill-serve the needs for cross-road wildlife movement in Vermont. While there is a need to refine our understanding of the influence of structure design characteristics on wildlife through-passage, the modified framework that relates structure size and species use and insights about the apparent influence of some site characteristics on wildlife use will likely prove useful for informing future projects aimed at increasing the permeability of highways in Vermont for wildlife.

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Introduction

Roads and wildlife impact each other in mutually detrimental ways. There are thousands of miles of permanent roads in Vermont (Anderson and Sheldon 2011), which along with associated development, are significant barriers for wildlife movement and a source of mortality for many species. Also, vehicle-wildlife collisions create extensive vehicle damage and human deaths; eighteen people have lost their lives in accidents with moose in recent years in Vermont, roughly averaging one human fatality per year (VT F&W). In the United States overall, an estimated one to two million collisions occur each year between cars and large, wild animals[1]. These issues affect the safety of wildlife and humans and impair the connectedness of habitats for wide-ranging terrestrial throughout and beyond Vermont, yet road corridor management options to encourage the movement of wildlife underneath through bridges and culverts instead of over roadways have not been thoroughly researched in the Northern Appalachians.

The importance of this issue is highlighted by the increasingly urgent conservation need for regionally connected habitat for wildlife. By decreasing the habitat-fragmenting barrier effect of major road corridors, wildlife movement between large forested habitat blocks will increase, and this will help maintain genetic diversity of wildlife populations and enable movement-mediated adaptation to unpredictable habitat changes anticipated to occur because of climate change. A statewide highway infrastructure managed to increase wildlife permeability in key areas that link habitats separated by road corridors, and in turn, tie together a habitat network that links regionally significant habitat areas (such as between the Green and Adirondack Mountains) is a key part of enabling this adaptation need.

The phenomenon of the use of transportation structures for under-road movement by wide-ranging wildlife has not been the topic of extensive systematic research in the eastern US. The mosaic of large temperate forest habitat blocks, agricultural valleys, scattered development, and perennial rivers and streams conveyed under roads by culverts and bridges in Vermont and Northern Appalachian forests constitute a little-studied setting for this issue.

This project conducted research to generate recommendations for road corridor management aimed at increasing the frequency of wildlife movement under highways through bridges and culverts. Similar research conducted in the Western US has documented that wildlife do use some bridges and culverts to move under roadways, and this body of work has been synthesized into a framework describing the characteristics of structures that are more likely to encourage use by wildlife species groupings (referred to as *movement guilds*; Passage Assessment System (PASS); Kintsch and Cramer 2011; Shilling et al 2012). This framework also includes a description of potential species use of transportation structures across a range of different sized structures in a structure-retrofit context (For example species *x, y*, and *z* may potentially use structures of size class *a* if retrofitted to optimize the potential for wildlife use). An attempt to modify this framework for application in Vermont was made by Shilling et al (2012).

[1] *According to Wildlife-Vehicle Collision Reduction Study: Report to Congress (FHWA-HRT-08-034), an estimated one to two million collisions occur each year between cars and large, wild animals in the United States. This presents a real danger to human safety as well as the viability of some wildlife populations.*

This project designed and implemented a game camera monitoring system to detect and assess the frequency of movement through bridges and culverts on major roadways in Vermont by wide-ranging terrestrial mammals. Results were used to assess the ability of the Shilling et all (2012) framework to characterize these relationships in ways that are applicable to and informative for road-corridor management in Vermont to 1) enhance the connectedness of the landscape across road corridors for wide ranging mammals; and 2) reduce vehicle-wildlife collisions. For example, if a particular stretch of road is known to have substantial wildlife movement over the roadway, and a nearby bridge, culvert or other structure is due for an upgrade, project results could help make the case for replacing or retrofitting a structure in ways that will encourage the movement of wildlife under the road as opposed to across the roadway. Similarly, where roads form near-impermeable wildlife barriers between otherwise large blocks of forested habitats, data-based guidance on improving existing culverts and bridges for wildlife movement may restore habitat connectivity in ways that can specify project-specific benefits for groups of species.

Methods

Site Selection and Game Camera Installation

We identified 23 bridges and culverts to collect data on wildlife *through-passage* with game cameras, where a through-passage is the movement of an animal under a roadway through a culvert or bridge.

To select study sites, we examined all bridges and culverts within road-corridors that lay within modeled "high probability wildlife movement pathways"[2] that connect large forested habitat blocks in Vermont across busy road corridors. We chose sites within two regionally-significant habitat Staying Connected Initiative[3] "linkage" areas: The Green Mountains to Adirondacks Linkage in Rutland County, VT, and the Worcester Mountains to Northeast Kingdom linkage in northeast VT. We specifically selected structures large enough to accommodate a set of moderate to wide-ranging "focal species" by selecting sites sufficiently large enough to accommodate the smallest mammals of interest (>4' width and > 15 feet structure area (width x height)).

We first mapped and then visited all the transportation structures that met the spatial and size criteria described above along state, US, and interstate highways in these linkage areas. To screen structures for likelihood of use by wide-ranging wildlife, we used "fatal flaws" criteria from the Passage Assessment System (PASS; Kintsch and Cramer 2011) to evaluate culverts for potential usability by at least one PASS movement guild from Shilling et al (2012) that included species characterized as "moderate mobility" or greater.

All structures visited were ranked from 1 to 4 based on PASS-derived "usability criteria" that facilitate or discourage wildlife use:

[2] Otherwise known as "Structural Pathways" in Staying Connected Initiative terminology.
[3] A regional partnership in the Northern Appalachians focused on maintaining and restoring connectivity between habitats for wildlife.

- Fluvial geomorphic characteristics that encourage or impair wildlife movement (e.g. perched culverts, high gradient culverts, etc).
- Upstream and downstream habitat/cover in proximity to the structure
- Proximity and type of development to structure
- Other nearby human uses/disturbances
- Overall accessibility of culvert entrance and exits (blocking vegetation, steepness of the valley walls surrounding the channel)
- Water depth and water coverage (degree of inundation) inside of the structure (are there any dry or shallow passable areas?)

Over 200 structures were assessed for camera placement with 23 sites chosen for camera establishment (Figures 1 a- d; Table 1).

Cameras were deployed at sites in two phases. The first set of 11 sites were identified and established between May 15 and June 5, 2014. A second set of 12 sites were established between March and June 2015.

ReConyx PC900 cameras were used to detect wildlife. Eighty -four cameras were purchased, tested for reliability and consistency before deployment, and then mounted on trees, bridge abutments, or, if no suitable mounting structure was present, on posts dug into the ground between 8 – 50 feet from the picture frame background (see Appendix A). Since we used best available mounting locations for cameras, there was a good deal of variability in the positioning on the cameras with respect to structure openings. Cameras were oriented so that they would be triggered by an animal movement within and, whenever possible, near structure openings. At smaller culverts, a camera was focused on both ends of the culvert to capture exits and entrances in either direction, thereby creating redundant capability to detect through-passages. On two larger bridges (128’ and 235’ wide), cameras were deployed to achieve spatial detection capability across the entire width of the structure on the exit and/or entrance side, but without redundant (both entrance and exit) detection capability. Cameras were set to take three photographs at a rate of 1 per second for each trigger. Cameras were mounted in metal security boxes, labeled, and locked with cable locks, and were visited approximately every 90 days to collect photographs and check on camera operability and battery levels.

Habitat-focused camera monitoring

To characterize wildlife presence in habitat adjacent to structures, we established 24 habitat-focused cameras across 6 sites (Table 1, Figure 1a-d). At each of these sites, in addition to the structure-focused cameras, habitat-focused cameras were installed on both sides of roadway in the best available habitat at distances of approximately 200ft and 1600 feet away from the structure (Figure 2). Some placement modifications needed to be made at some sites due to inability to get landowner permission on some parcels, and in one case, rescindment of camera siting permission in mid-project by a landowner. Cameras were focused in locations that appeared to favor wildlife movement (game trails, near wetlands, on seldom-used logging roads, etc).

Table 1. Twenty-three camera sites and related characteristics for monitoring wildlife use of transportation structures. Sites that hosted habitat-focused cameras are in italics. See Appendix A for additional information on site characteristics.

Structure	**Road**	**Town**	**Size class**	**Structure Substrate**	**Structure type**
I-91a	I-91	Sheffield	small	Corrugated	Pipe
14-102	VT 14	Hardwick	small	Natural/concrete	Arch culvert
16-13	VT 16	Glover	small	Corrugated	Pipe
122-24	*VT 122*	*Glover*	*small*	*Natural/concrete*	*Box culvert*
16-14	VT 16	Glover	small	Natural/concrete	Box culvert
2-90	*US 2*	*Cabot*	*med/lg*	*Natural/concrete*	*Arch culvert*
12-92	*VT 12*	*Elmore*	*med/lg*	*Natural/concrete*	*Box culvert*
114-22	*VT 114*	*Brighton*	*small*	*Natural/concrete*	*Box culvert*
12-83	VT 12	Worcester	med/lg	Natural/concrete	Span
15-51	VT 15	Wolcott	med/lg	Natural/concrete	Span
114-20	VT 114	Newark	med/lg	Natural/concrete	Span
4-12-17	US 4	Ira	small	Corrugated	Pipe
15-76	VT 25	Cambridge	small	Natural/concrete	Box culvert
I91bE	I-91	Sheffield	small	Corrugated	Pipe
I91bW	I-91	Sheffield	small	Corrugated	Pipe
7-110	*US 7*	*Pittsford*	*small*	*Natural/concrete*	*Box culvert*
I91-101-3s	I-91	Sheffield	small	Corrugated	Pipe
4A-13	VT 4a	Ira	med/lg	Natural/concrete	Span
I91-101-2s*	I-91	Sheffield	small	Corrugated	Pipe
103-53	*VT 103*	*Shrewsbury*	*med/lg*	*Natural/concrete*	*Box culvert*
30-84	VT 30	Poultney	med/lg	Natural/concrete	Span
133-13	VT 133	Ira	med/lg	Natural/concrete	Span
73-5	*VT 73*	*Sudbury*	*med/lg*	*Natural/concrete*	*Span*

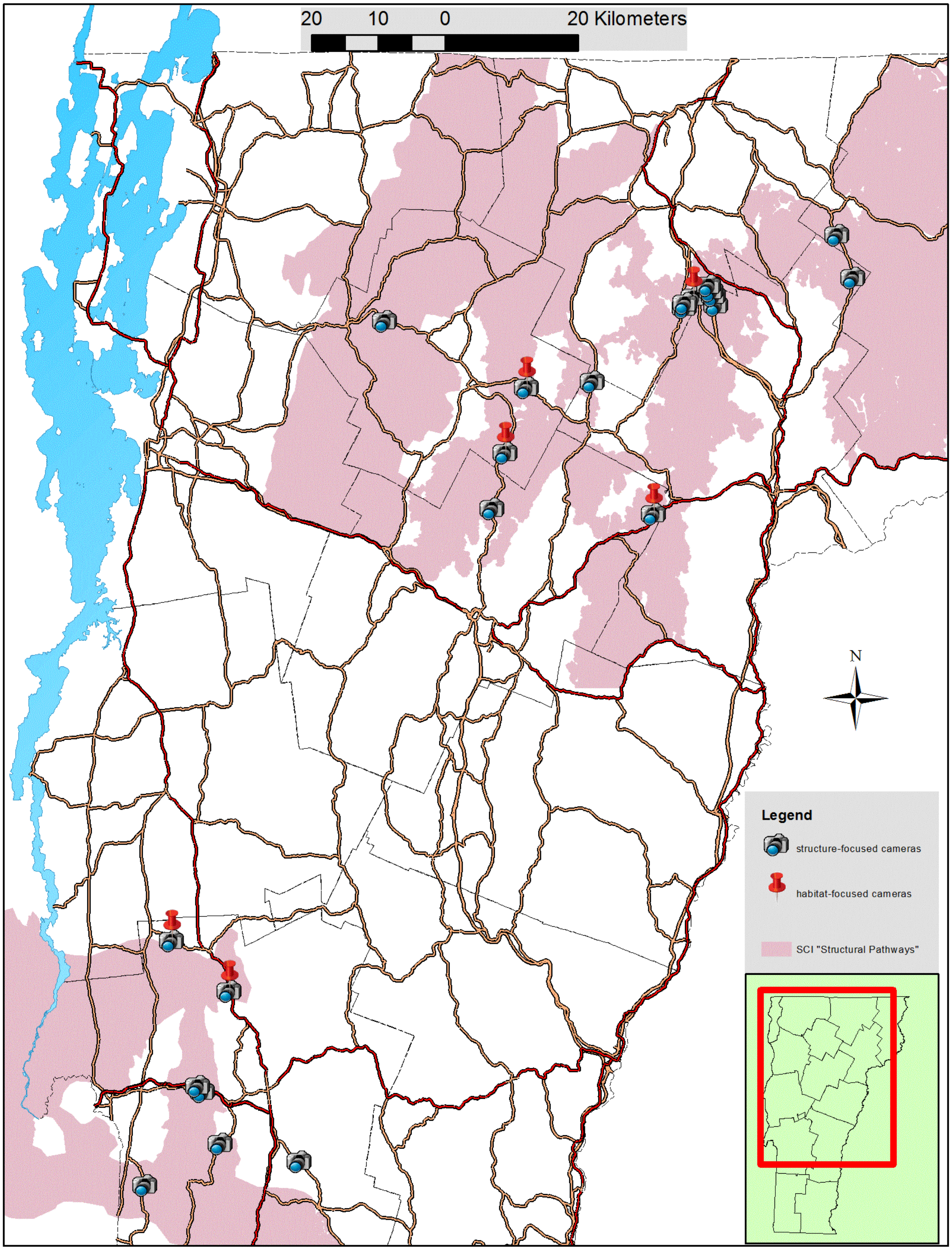

Figure 1a: Map of site locations and Staying Connected Initiative linkage areas in Vermont.

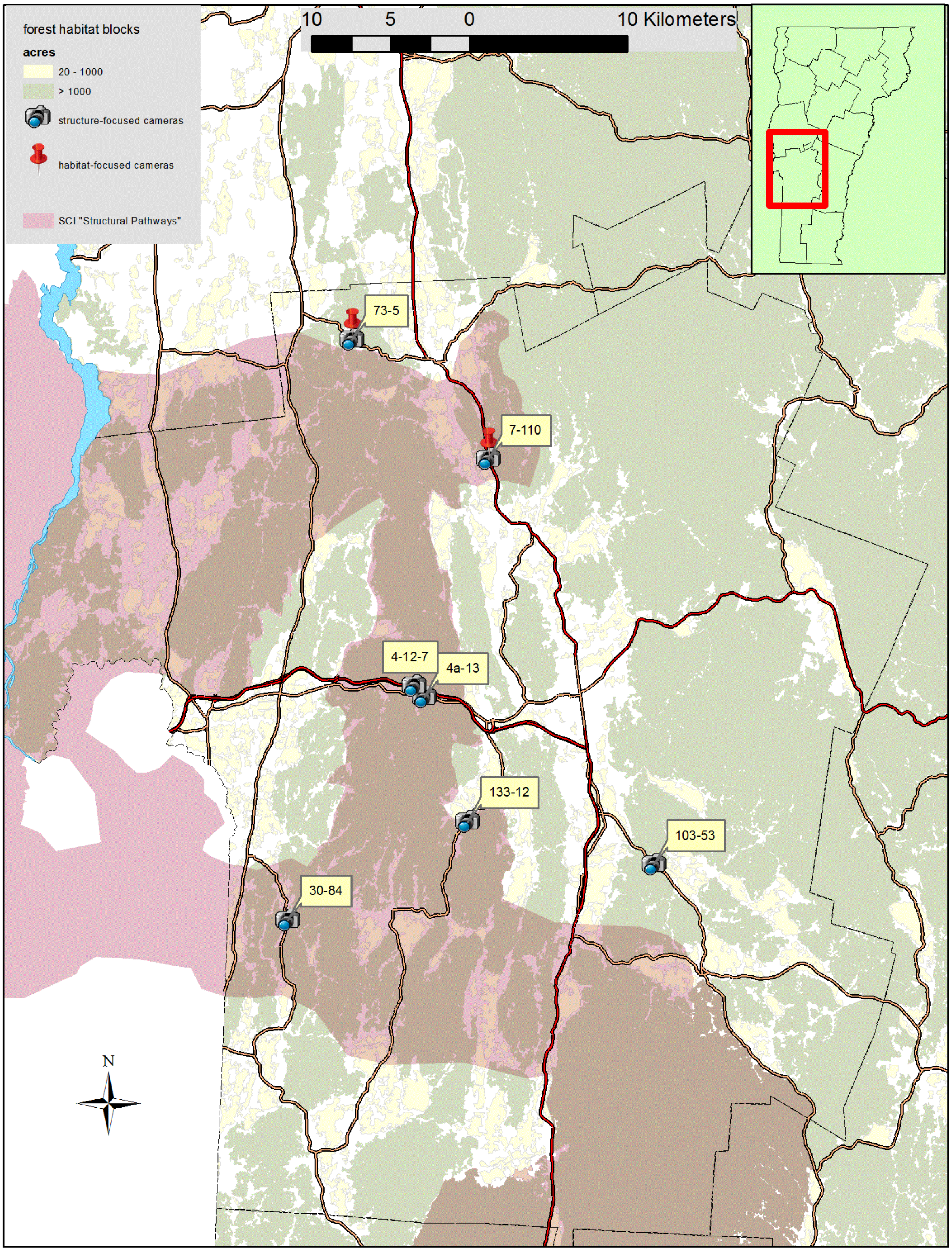

Figure 1b: Sites in the Greens-Adirondacks linkage in Rutland County, VT, with SCI “structural pathways” and forest habitat blocks.

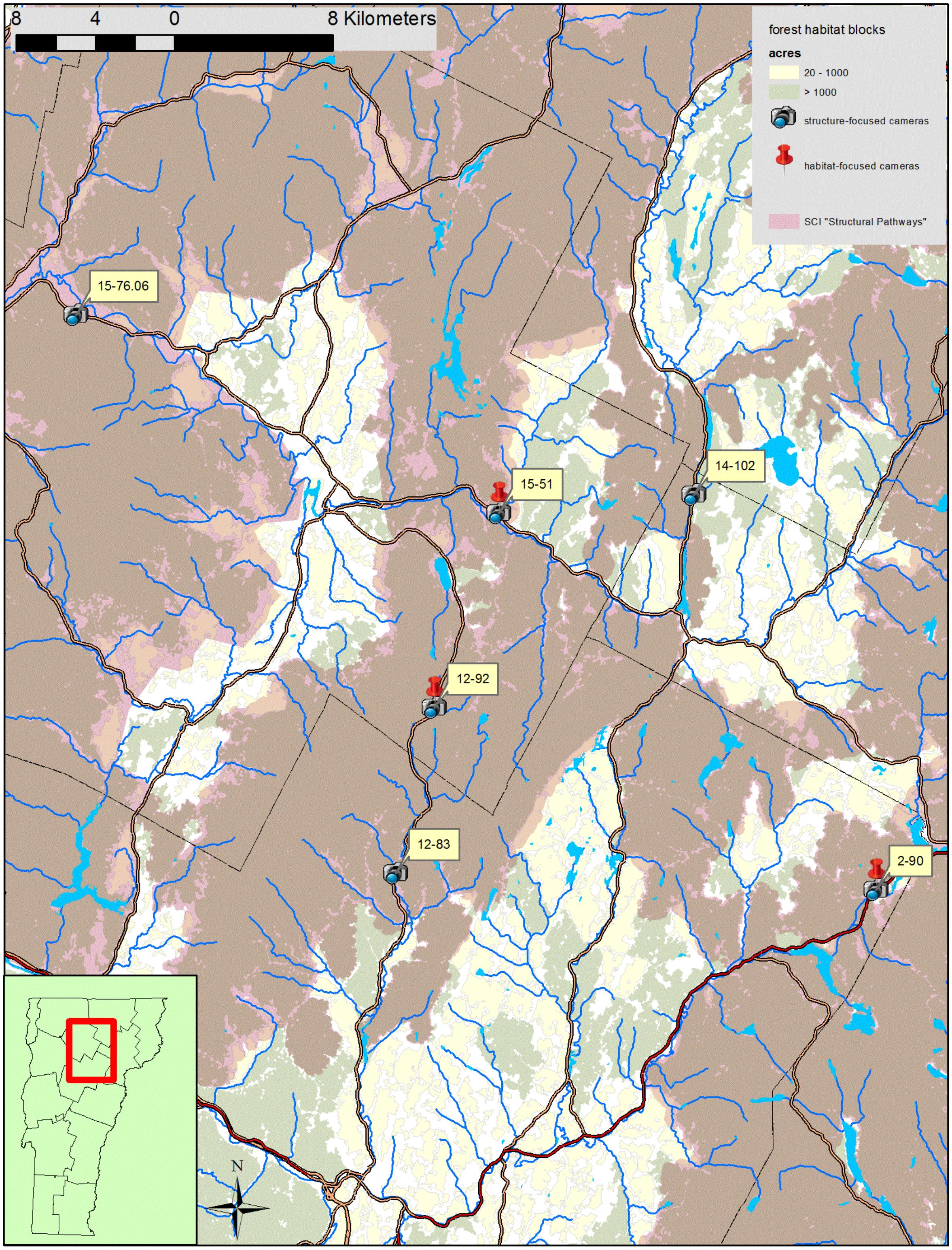

Figure 1c: Sites in the western part of the Worcesters to Northeast Kingdom linkage in VT, with SCI "structural pathways" and forest habitat blocks.

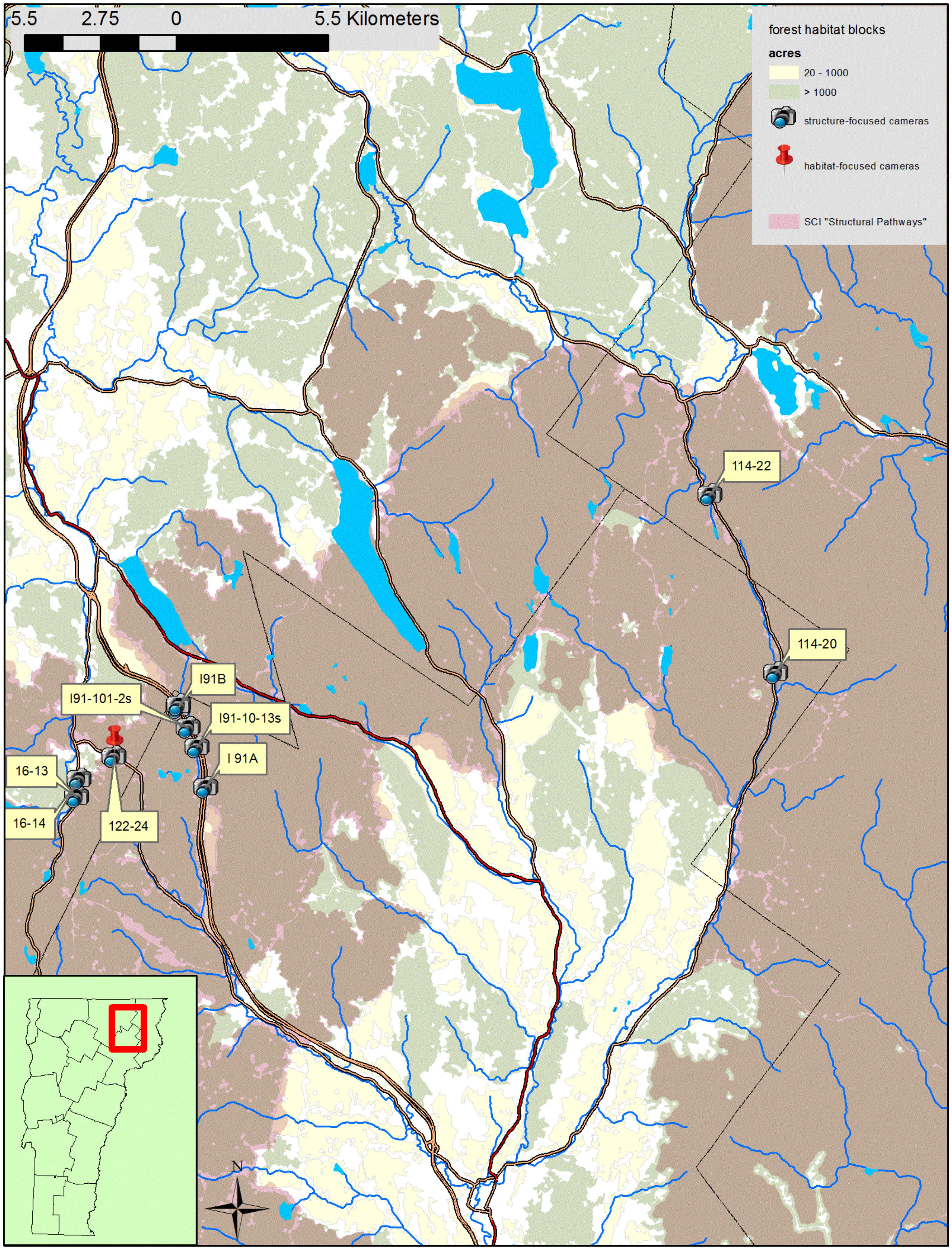

Figure 1d: Sites in the eastern part of the Worcesters to Northeast Kingdom linkage in VT, with SCI "structural pathways" and forest habitat blocks.

Figure 2: Placement design of game cameras at sites with both habitat and structure-focused cameras. Habitat-focused cameras were set approximately 200’ and 1600’ from the road.

Data Management

To record wildlife photo-data, we visually scanned all photos for the presence of wildlife and recorded each detection in a database created for this project. We recorded one detection for each animal photographed. If an identifiable individual was photographed within 10 minutes of its initial photograph, we did not record a separate detection. Other than this detection recording rule, no effort was made to link detections to specific individuals.

Some cameras were oriented such that they were liable to false triggers from leaves and vegetation blowing in the wind, sunlight reflecting off water, etc., and would record up to the capacity of an SD card over the 3-month camera check interval, recording up to 30,000 false-trigger photos. To process these photos, we sometimes created an .avi movie file from all the pictures and set a frame speed of 6 frames per second, which proved slow enough to identify individual wildlife detections. This greatly improved our photo processing efficiency and helped minimize processor fatigue.

We identified to species (mink (*Neovison vison*), long tailed weasels (*Mustela frenata*) and short tailed weasels (*M. ermine*) were sometimes difficult to differentiate, and were therefore combined into a “small weasel” category for analysis) and recorded each wildlife photo detection, and then cross referenced all detections at a site by date, time, and location to determine and code individual wildlife *through-passages*, with one wildlife through-passage consisting of photographic evidence of one animal completely moving under a road through a transportation structure. A through-passage was recorded into our database when at least one photograph depicted an animal either entering or exiting a structure, providing there was no subsequent photographic evidence of an immediate “turn around” (e.g. an entrance and immediate exit from the same end of the structure).

To calculate the frequency of structure use, the total number of through-passages at a site were divided by the number of structure monitoring days (where one monitoring day = a day where at least one structure-focused camera at a site was operational). Through-passage frequencies were reported per 100 monitoring days.

We recorded and analyzed detection and through-passage data for a set of 13 focal species (Table 2) comprised of larger terrestrial mammals that are mostly wide-ranging and/or are of some conservation interest.

Table 2: List of focal species and number of sites detected

Focal species	# sites	Focal species	# sites
Coyote	6	Grey fox	1
Deer	17	Otter	3
Moose	1	Red fox	8
Black bear	3	Skunk	9
Bobcat	10	Small weasel	19
Fisher	8		

Results

Wildlife Detections and Through-Passages

Structure-focused game cameras recorded a total of 418,000 photos over 39,940 monitoring days across all sites, and yielded 738 detections of 13 focal species and 573 focal species through-passages (Table 3). Detections of an additional 11 secondary species were recorded (Table 4), while small mammals (mice, voles, chipmunks, squirrels) and other birds (wood ducks, woodcock, mergansers, swallows, and great blue heron (including one that used a culvert for through-passage!)) were photographed but not recorded in our project database.

At some sites, secondary species were exceptionally numerous. For example, at Site 16-14 in Glover, we literally recorded hundreds of domestic cat and raccoon through-passages. We ceased coding these into the database on account of the inordinate processing time required, instead focusing our efforts on species that are more relevant to the conservation needs that we were seeking to address. Raccoons were particularly abundant across all sites, and were recorded using almost all structures in this study to move under roadways, including structures that had no through passage data of focal species.

There were substantial differences in mean species through-passage frequencies across all sites (Figure 3). Deer had by far the highest mean through-passage frequency of all focal species (2.35 per 100 days). Bobcat, fisher, and small weasel had more moderate through-passage frequencies (between 0.23 and 1.11 per 100 days). Grey fox, red fox, skunk, otter, and coyote all had low mean through-passage frequencies (< 0.16 per 100 days), and only a small number of detections and no through-passages were recorded for moose or black bear.

Total focal species through-passage frequencies differed substantially between sites (Figure 4). Ten sites had low through passage frequencies (< 1.00 per 100 days, two of which had no focal species through-passages at all). Moderate or high through-passage frequencies were recorded for the 11 sites (between 1.50 and 36.39 through-passages per 100 days). Site 30-84 hosted an anomalously high through-passage frequency (36.39 through passages per 100 days) compared to other sites, mostly due to a high frequency of use by deer.

Habitat-focused camera monitoring

At the six sites where habitat-focused cameras were established, we detected all 13 focal species (Table 5). Similar to the results from structure-focused cameras, deer were detected most frequently (Table 6). Also, in contrast to structure-focused cameras, habitat-focused cameras recorded numerous bear and moose detections. All sites had similar mean focal species detection frequencies, except Site 7-110, which was notably higher (Table 6). Results at this site were driven by a high frequency of deer detections.

Table 3: Number of detections (both through-passages and approaches) of focal species by site.

species	I-91A	2-90	12-83	12-92	14-102	15-51	16-13	16-14	122-24	114-22	114-20	I91-101-3s	4a-13	30-84	103-53	133-13	4-12-7	I91-BE	I91-BW	7-110	15-76	73-5	I91-101-2s	**Total**
Coyote	3	0	0	0	0	2	0	0	1	1	0	0	0	0	0	11	0	7	0	0	0	0	0	**25**
Deer	1	0	7	0	9	0	2	1	0	7	0	0	34	161	3	13	9	5	3	20	9	49	1	**334**
Moose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	**1**
Bear	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	**3**
Bobcat	2	0	0	0	0	0	0	0	1	0	16	0	32	1	1	12	2	0	3	0	0	1	0	**71**
Fisher	5	0	0	0	0	0	9	0	35	1	0	0	0	0	1	0	0	2	1	0	1	0	0	**55**
Grey fox	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Otter	3	0	0	0	0	0	0	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	**8**
Red fox	1	1	0	0	0	2	2	8	0	1	0	0	0	8	0	0	0	0	0	0	0	8	0	**31**
Skunk	0	2	1	0	0	0	0	16	2	0	0	0	1	2	1	1	1	0	0	0	0	0	0	**27**
S weasel[1]	24	2	0	3	2	2	53	38	5	0	7	14	1	11	1	1	2	0	7	1	3	0	4	**181**
Total	**39**	**5**	**10**	**3**	**11**	**6**	**66**	**63**	**45**	**12**	**23**	**17**	**68**	**183**	**7**	**38**	**14**	**16**	**15**	**21**	**13**	**58**	**5**	**738**
# days[2]	758	750	758	758	753	748	766	741	749	756	751	401	481	477	435	481	440	400	400	424	442	410	200	**13,279**
Freq[3]	5.1	0.7	1.3	0.4	1.5	0.8	8.6	8.5	6.0	1.6	3.1	4.2	14	38.0	1.6	7.9	3.2	4.0	3.8	5.0	2.9	14.0	2.5	**5.6**

[1] combined detections of mink, ermine, and long tailed weasel

[2] number of camera monitoring days at a site

[3] Frequency of detections per 100 monitoring days

Table 4: Number of sites at which secondary species were detected.

Secondary species	# sites
Raccoon	21
Woodchuck	15
Domestic cat	9
Domestic dog	6
Lagomorph	9
Muskrat	5
Opossum	1
Porcupine	2
Turkey	5

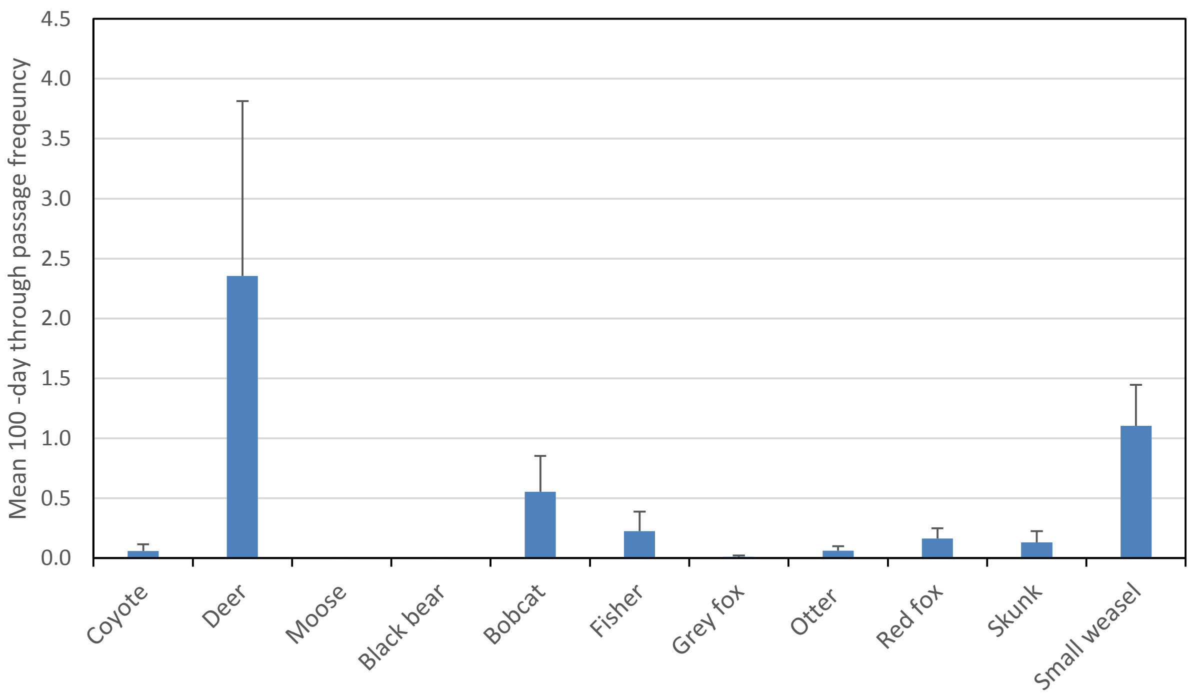

Figure 3: Mean (SE) Passage events per 100 days for each focal species across all sites.

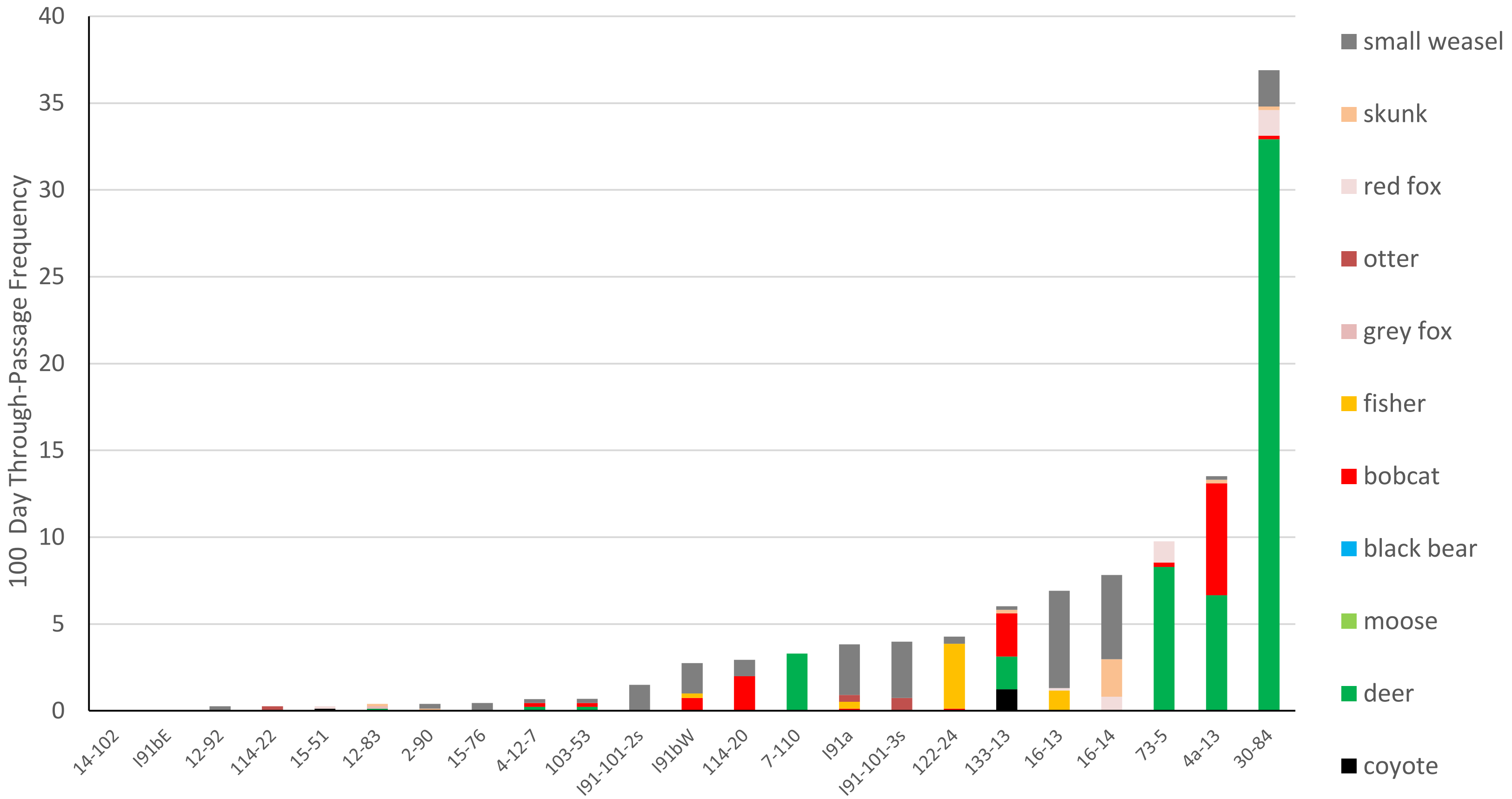

Figure 4: Focal species 100 day through-passage frequency at each site, color coded by species.

Table 5: Focal species detections at the 6 sites with habitat-focused cameras.

Species	total detections	% of detections
coyote	180	13.9
deer	879	67.7
moose	38	2.9
black bear	24	1.8
bobcat	31	2.4
fisher	54	4.2
grey fox	5	0.4
otter	22	1.7
red fox	40	3.1
skunk	13	1.0
small weasel	13	1.0
Total	**1299**	

Table 6. 100-day detection frequency of species from habitat-focused cameras (cameras in habitat at 200 and 1600m away from the structure).

species	site							
	122-24	12-92	15-51	2-90	7-110	73-5	mean	SE
coyote	13.88	12.47	7.04	4.73	8.32	9.69	9.36	1.39
deer	16.01	24.27	39.59	16.75	227.84	35.16	59.94	33.81
moose	0.00	14.11	0.28	0.00	0.42	0.00	2.47	2.33
black bear	0.84	4.06	0.28	0.34	3.39	0.59	1.58	0.69
bobcat	0.00	1.10	0.00	1.76	3.95	3.62	1.74	0.70
fisher	2.22	1.19	0.59	0.00	0.00	0.00	0.67	0.37
grey fox	0.55	0.00	0.00	0.00	0.85	0.00	0.47	0.25
otter	0.00	0.00	0.00	0.00	0.00	6.69	1.11	1.11
red fox	0.82	0.32	4.02	4.82	0.00	0.30	1.72	0.87
skunk	0.56	0.00	0.64	0.00	0.00	1.15	0.39	0.19
small weasel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**41.71**	**57.97**	**53.26**	**29.08**	**253.47**	**74.07**	**84.93**	34.27

At sites where few or no through-passages were recorded by structure-focused cameras (Sites 15-51, 12-92, and 2-90), focal species detections from habitat-focused cameras were not comparatively low enough compared to all six sites (Figure 5) to suggest a strong link between lack of through-passages at structure-focused cameras and an absence of the species from nearby habitats.

Also, mean detection frequencies of focal species, focal species without deer, and bear, bobcat, fisher, and moose ("BBFM") all increased as distance from transportation structures increased (Figure 6), illustrating the barrier effect of the road corridors that bisect the camera monitoring sites: focal species were detected much more frequently in habitat away from the transportation structures than at the transportation structures.

Movement Guild-based Analytical Framework

Movement guilds were developed by Kintsch and Cramer (2011) to evaluate the potential benefit of transportation structure retrofit/replacement for structure-specific wildlife passage mitigation projects in terms of potential species use. This framework was modified for Vermont by Shilling et al (2012); (Table 7). We analyzed data to assess how well this framework described observed focal species use patterns of existing transportation structures that met PASS-derived wildlife "usability" criteria.

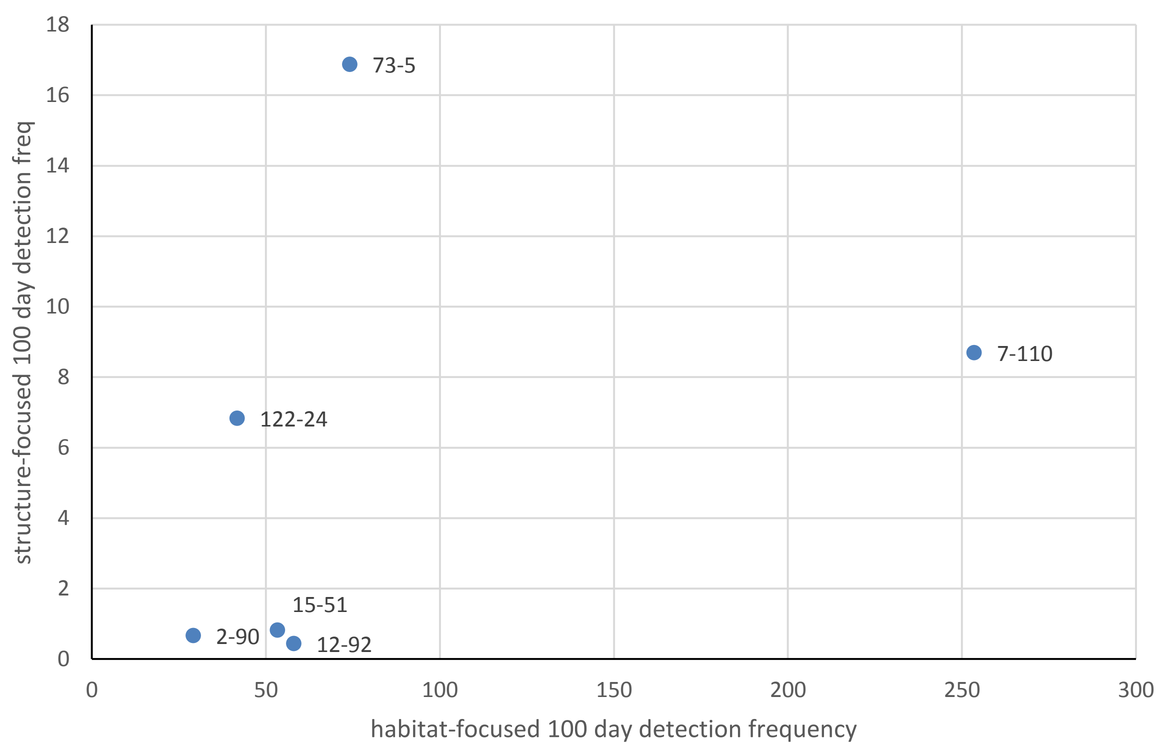

Figure 5. Plot of detection frequencies from structure-focused cameras vs. habitat focused cameras at 6 sites with habitat cameras. Data points labeled by their respective sites.

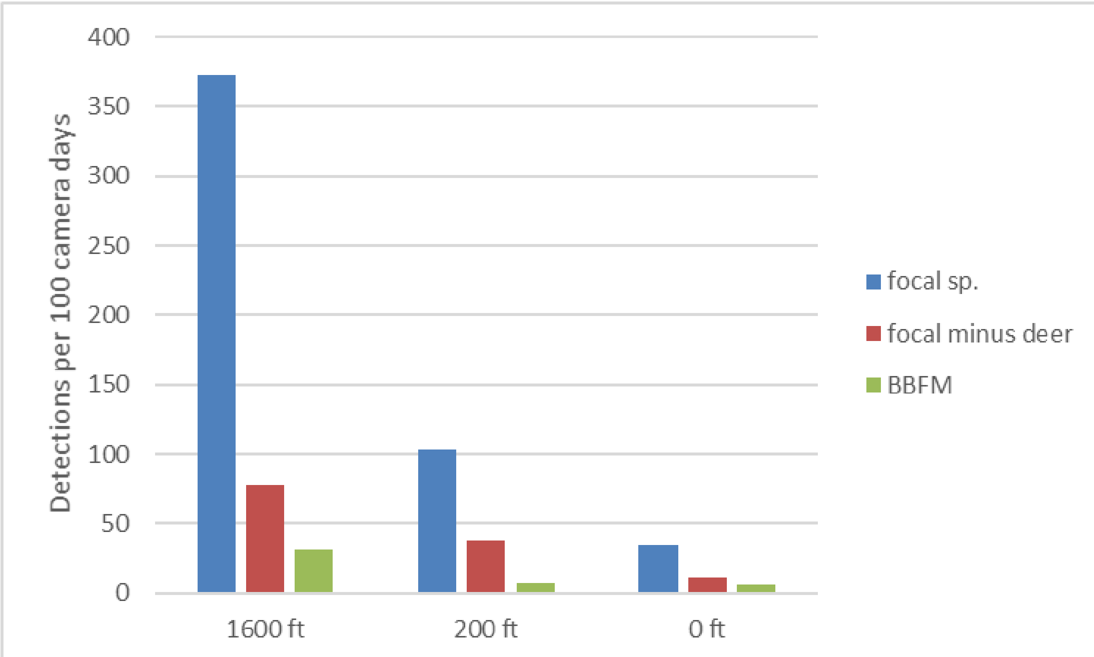

Figure 6: Mean 100-day detection frequencies from six sites with habitat-focused cameras by distance from the monitored transportation structure. Means for three different species groupings are shown: all focal species, all focal species except deer; and bobcat, bear, fisher and moose (BBFM).

Table 7: Hypothetical size class/movement guild species composition framework for potential focal species use of transportation structures across a range of structure types and sizes. Derived from Shilling et al (2012).

Size Class	Structure	Movement guild	species
Small underpass	pipe, box, and arch culverts; 3-6' wide and < 8' height	Moderate Mobility Small Fauna (MMSF)	small weasel, fox, otter, fisher
		Adaptive High Mobility Fauna (AHMF)	bear, coyote, lynx, bobcat
Medium underpass	Larger culverts between 5' and 8' width and height	Moderate Mobility Small Fauna (MMSF)	small weasel, fox, otter, fisher
		Adaptive High Mobility Fauna (AHMF)	bear, coyote, lynx, bobcat
		Adaptive Ungulates (AU)	deer, moose
Large underpass	bridge spans, large culverts > 10' wide, > 8' high	Moderate Mobility Small Fauna (MMSF)	small weasel, fox, otter, fisher
		Adaptive High Mobility Fauna (AHMF)	bear, coyote, lynx, bobcat
		Adaptive Ungulates (AU)	deer, moose
		High Openness High Mobility Carnivores (HOHMC)	cougar, wolf

However, we first found omissions and inconsistencies in Shilling et al's (2012) movement guild tables that needed to be resolved in order to develop movement guilds for our study: a failure to mention or place fisher within any of the movement guilds, and the classification of bobcat in two different movement guilds (AHMF and MMSF) on 2 different tables. We assigned fisher to the MMSF movement guild because of its need for cover for movement, and assigned bobcat in the AHMF (Table 7). Both these movement guilds are theoretically able to use structures of all size classes, with the principal difference being that MMSF species generally have greater needs for cover around the structures.

Since Shilling et al's (2012) movement guild framework covers a broader spectrum of taxa than our study (including, for example, movement guilds of smaller non-wide ranging taxa such as amphibians, rodents, reptiles, etc.), we adapted the framework to be specifically applicable to the transportation structure use of wider-ranging mammals (Table 7). For example, the Moderate Mobility Small Fauna (MMSF) guild is theoretically able to use structures <5' wide in Shilling et al (2012), yet consists of both wide ranging species used for this study (bobcat, otter) and smaller species excluded from this study (cottontail and rattlesnake). Since our analytical group of MMSF species is larger and wider ranging on average compared to Shilling et al's (2012) MMSF, we increased the size dimension criteria for small structures to <6 feet wide. While this distinction is important to note when interpreting our analysis, it ultimately was of minor consequence in terms of predicting movement guild use of transportation structures, because the most critical dimension distinction between small and medium size classes is the height threshold that allows Adaptive Ungulates (moose and deer) to use a structure (> 8' high), rather than width.

Refining the transportation structure size class-movement guild analytical framework

Classifying structures into size classes

When we attempted to classify the transportation structures at our study sites into size class categories as defined in Shilling et al (2012), three of our study sites did not fit neatly into the structure size class criteria. Site 114-20 in Newark, VT is wide enough (19.5') to be placed in the "large" size class category. However, the river channel itself under the bridge is always completely inundated with swift-moving water at least 1' deep, and is unsuitable for wildlife movement. The structure has two 1.2' wide concrete ledges on the sides of the bridge abutments that are almost always dry (Figure 7), which are the only movement surfaces under the structure available for terrestrial wildlife. Because there is only 5' of clearance above these ledges, the structure was instead placed in the "small" size class, despite the structure's width. Site 73-5 in Sudbury crosses over Otter Creek on Rt 73 and is by far the longest bridge (220 ft) in our set of study sites, and spans the wide mainstem of Otter Creek and a broad dry floodplain. While far surpassing the width criteria for a the "large" size class, this structure did not quite meet the height criteria needed to be included in the "medium" or "large" size class categories (there was only between 5 -7' of clearance between the likely movement surface (the dry floodplain) and the structure). We nevertheless decided to assign this structure in the "large" size class because of its width and relatively large openness ratio. At its greatest clearance, (7'), it is just less than the minimum height clearance needed to be categorized as "large" or "medium". Finally, Site I91 101-2s was a pipe 7' in diameter, but was classified as "small" because it did not meet height criteria for medium/large.

Figure 7. Concrete “abutment shelf” at Site 114-20 in Newark

Structure Size Classes and Species Movement Guilds

We integrated Shilling et al’s (2012) three tables describing relationships between transportation structure size classes and movement guild species composition (Table 7), and then compared this with our camera detection data.

This initial comparison revealed a need to modify the framework for further analysis of project data. Because 1) Shilling et al’s (2012) HOHMC guild is composed of species that are presumed extirpated in Vermont (wolf and cougar); and 2) we only collected through-passage data for 1 species (deer) in the AU guild, expected species use of large size class structures was identical to expected species use of medium structures. We therefore combined medium and large size class structures into one “medium/large” size class (Table 8). This also had the benefit of evening out the number of structures in each category, as we had trouble identifying medium-sized structures that met our criteria during the site selection process.

Game camera results from sites with habitat-focused cameras also indicated the need for an additional framework modification: to place coyote in a different movement guild. A plot of through-passages frequencies vs. detection frequencies at the six sites with habitat-focused cameras by species (Figure 8) revealed a pattern suggesting that coyotes are more appropriately assigned to the HOHMC guild

Table 8: Movement guild/structure size class analytical framework used for this study, modified from Shilling et al (2012). Species that were documented using structures for through-passages in this study are underlined.

Size Class	structure	Movement guild	species
Small underpass (13 sites)	pipe, box, and arch culverts; 3-6' wide and < 8' height	Moderate Mobility Small Fauna (MMSF)	small weasel, fox, otter, fisher
		Adaptive High Mobility Fauna (AHMF)	bear, lynx, bobcat
Medium/large underpass (10 sites)	culverts and bridges > 6' wide and > 8' high	Moderate Mobility Small Fauna (MMSF)	small weasel, fox, otter, fisher
		Adaptive High Mobility Fauna (AHMF)	bear, lynx, bobcat
		Adaptive Ungulates (AU)	deer, moose
		High Openness High Mobility Carnivores (HOHMC)	coyote, cougar, wolf

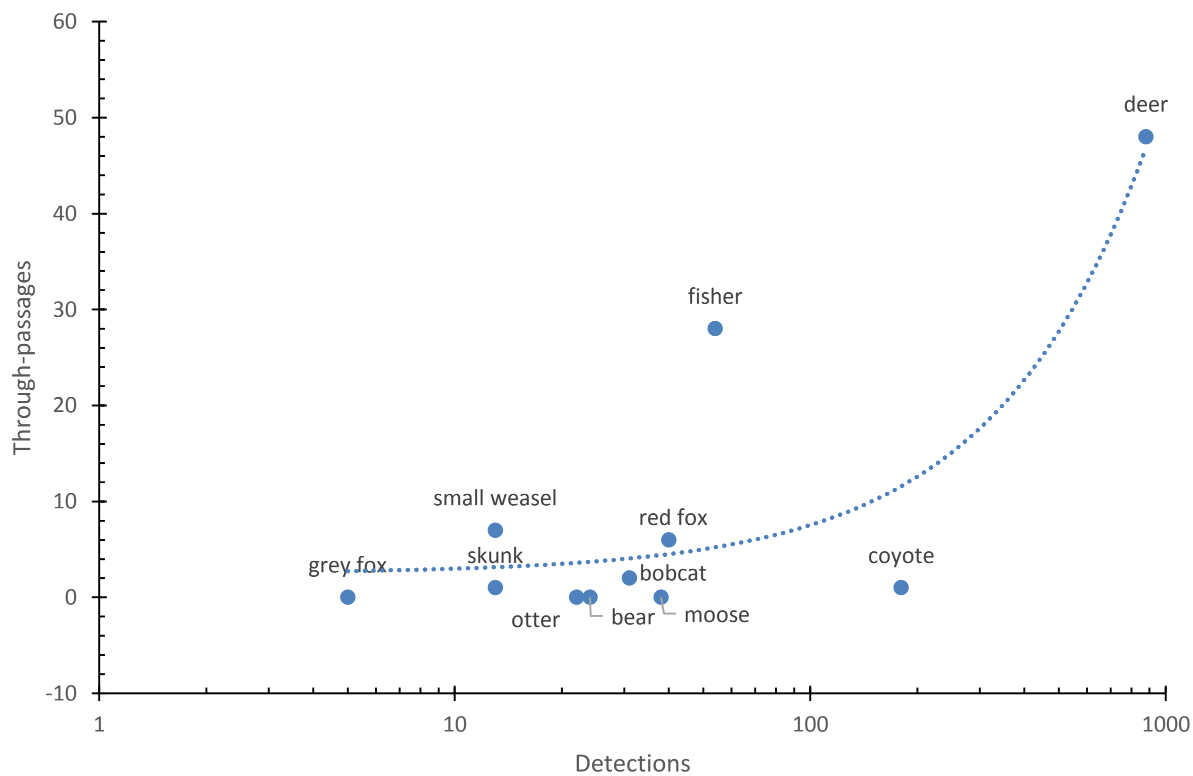

Figure 8: Plot of the number of through-passages vs. number of detections from all cameras at the 6 sites with habitat-focused cameras. Coyotes were detected with the fewest through-passages relative to the number of detections. Fisher were detected with the greatest number of through-passages relative to the number of detections, probably because of fisher's preference for moving through cover caused it to avoid the more open areas where habitat-focused cameras were sited.

than the AHMF guild, where it is placed in Shilling et al (2012). Because coyote through-passages were remarkably rare relative to the number of coyote detections from habitat-focused cameras, Figure 8 suggests that coyotes were not inclined to use transportation structures for road crossings compared to other species (using the best fit least-squares line Figure 8 as a reference). Also, the only coyote through-passage data we have are from large size-class structures. Given that Monzon et al (2014) documented a high degree of genetic introgression of eastern timber wolf genes into the genome of the eastern coyote, it appears that coyote behavior with respect to use of transportation structures may be similar to wolf behavior in key ways. We therefore moved coyotes from the AHMF to the HOHMC movement guild (Table 8).

Because of the shift of coyote to the HOHMC guild, when movement guild through-passage data were tabulated by movement guilds, three guilds consisted of data from only one species: bobcat in the AHMF, deer in the AU, and coyote in HOHMC (Table 8).

Through-passage frequency data analysis

Mean through-passage frequencies for each movement guild differed when calculated by structure size class (Table 9; Figure 9): AU movement guild species (deer) and HOHMC movement guild species (coyote) predominantly used only medium/large structures for through passage, while MMSF species (fisher, small weasel, red and grey fox, skunk) and AHMF species (bobcat) used structures in both size classes with similar frequency. This is consistent with our working hypothesis that would expect that AU and HOHMC would exclusively use medium/large size class structures, and that MMSF species would use structures in both size classes.

When movement guild through-passage frequencies were tabulated by movement guild groupings by expected size class structure use (Table 10), mean through passage frequencies and size class were not statistically independent (Pearson Chi-Square = 181.8; $p<0.0005$), suggesting that through-passage frequencies for movement guilds, when grouped by expected use of size class categories, were influenced by size class.

Species-specific differences are apparent when looking within size-classes. Most notably, in the MMSF, fisher and the “small weasel” group appeared to favor small underpasses over large underpasses (Figure 10). In the AHMF, mean through-passage frequencies for bobcat were much greater in large underpasses than small underpasses (Figure 10), but that may have more to do with a preference for dry surfaces, which were generally more available in the large size class structures in our study compared to small size class structure sites.

Variation of through passage data among sites

Focal species through-passage frequency differed substantially between sites (Figure 6). Ten of our 23 sites had very low or no through-passage use. Considering that we systematically selected sites that appeared most suitable for use by focal species for through-passages, this variation was greater than what we expected. To help interpret this variation, we collected data on 15 structural and site attributes (Table 11) to assess their value for explaining inter-site variation in through-passage data

Table 9: Mean (SE) through-passage frequency of movement guilds by size class.

Guild	Med/Large underpass		Small underpass	
	mean	SE	mean	SE
MMSF	0.86	0.43	0.86	0.43
AMFH	1.20	0.81	1.20	0.81
AU	6.26	3.98	6.26	3.98
HOHMC	0.17	0.15	0.17	0.15
Grand Total	**8.49**	**4.43**	**8.49**	**4.43**

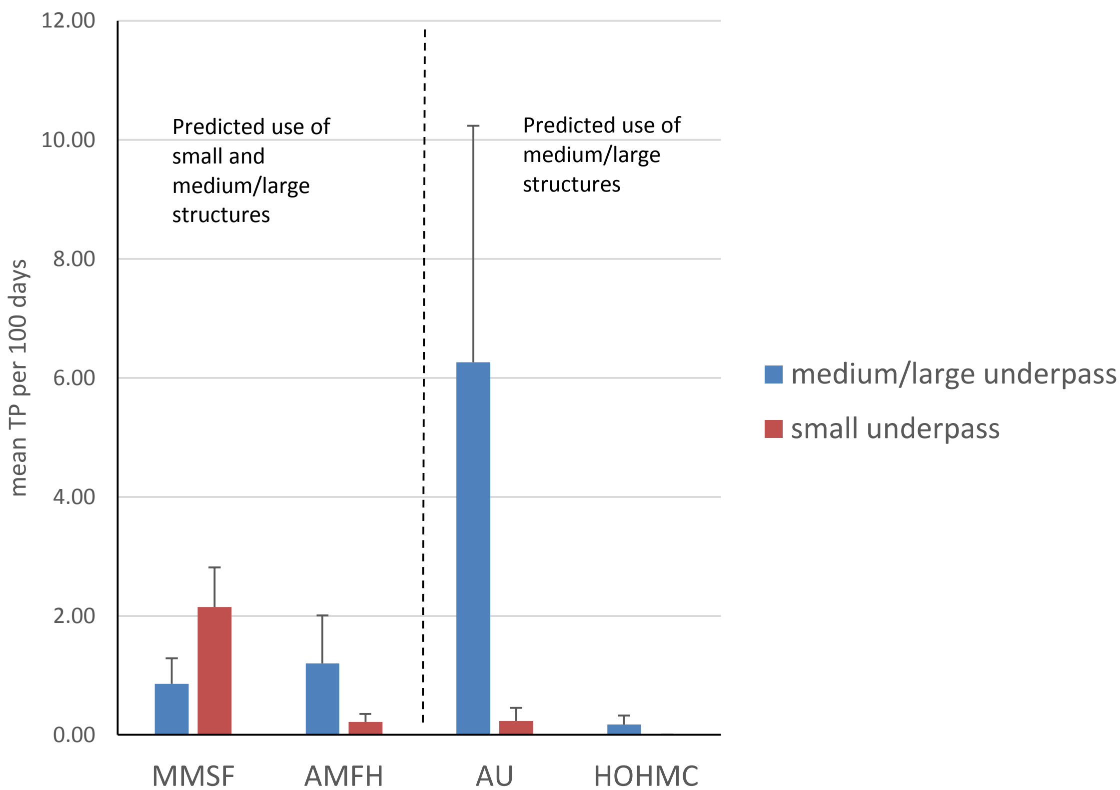

Figure 9: Mean (SE) movement guild through-passage frequencies sites by structure size class. Results are consistent with what we would expect to observe according to the revised movement guild/size class framework in Table 8. Tabulated through-passage frequencies by size class categories were not statistically independent (Pearson Chi-Square = 181.8; p<0.0005).

Table 10: Expected focal-species transportation structure through-passage use framework using modified structure size classes and movement guilds. Through-passage frequencies by expected size class use for movement guilds (small for MMSF and AHMF; medium/large for AU and HOHMC) were not statistically independent (Pearson Chi-Square = 181.8; p<0.0005).

	Structure Size-Class	
Movement Guilds	Small	Medium/Large
MMSF; AHMF	Yes	Yes
AU; HOHMC	No	Yes

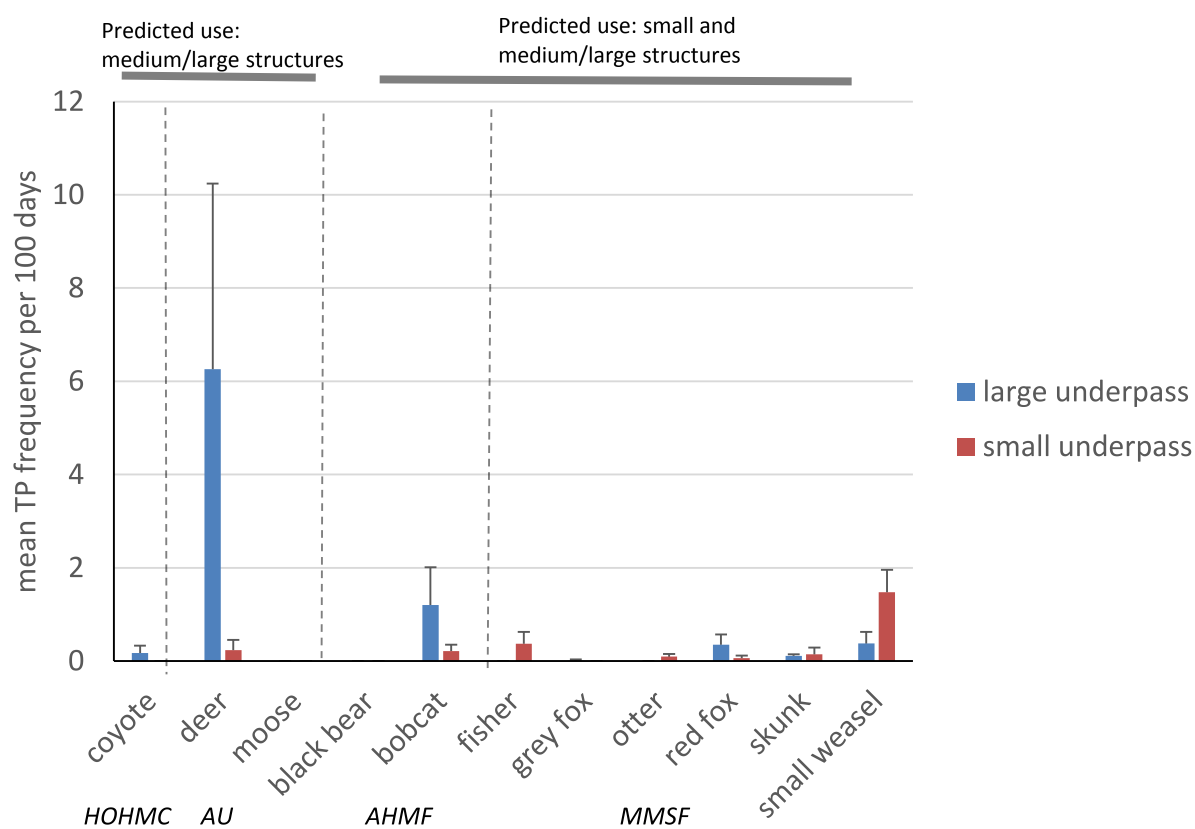

Figure 10. Mean 100 day through-passage frequencies per species by size class. Species are grouped according to movement guilds with guilds labeled below the x axis. Species with detections but no through-passages represented as zero data.

Table 11: site and structure attribute data collected for each site.

Attribute type	Attribute
structure attributes	structure length
	structure height
	structure width
	structure area (length x width)
	openness ratio (width x height x length)
	structure type (pipe culvert, box culver, arch culvert, span)
	substrate (flat vs. rounded)
	structure width to bankfull width ratio
site attributes	road elevation above movement surface
	light in structure
	Local block-connecting structural connectivity (diffuse, fragmented, pinched)
	distance to nearest forest blocks
	most likely movement surface
	surrounding land use
	Annual Average Daily Traffic (AADT)

Low though-passage frequency at two sites (Sites 12-83 and 2-90) appear attributable to pens of hunting dogs at nearby residences within 3/16 mile of the structure. These dogs likely elicited wildlife avoidance of these structures.

Results from an additional two sites with low through-passage frequency are probably attributable to unfavorable structural characteristics for wildlife passage. One of these sites (14-102 in Hardwick, VT) had excellent landscape context in an area of the Worcesters-NEK linkage where we were unable to identify any other potentially useable structures, but the structure proved too inundated (nearly entire culvert bottom continually inundated) and low (3' high) to be used by focal species in the MMSF and AHMF movement guilds. We did observe a number of raccoon through-passages at this site however. Another site (4-12-7) was probably too long to be regularly used by focal species. This structure is a 6' diameter corrugated pipe culvert that passes under east and westbound lanes of US 4 in Ira. The structure is by far the longest of all our sites (311' long), with a 10' break in the pipe that opens in the median of US 4. This site was chosen because of its strategic location directly between two large forest habitat blocks north and south of the US 4 corridor, and because it directly abuts state land to the north.

Low-through passage frequency at another three sites (Sites 15-51, 15-76, and also 2-90) appeared to be associated with an absence of continuous forested habitat (or structural connectivity) that directly connected forest habitat blocks on both sides of the road. Sites that had at least some degree of structural connectivity between forest blocks mostly had larger through-passage frequencies. These observations prompted us to look more closely at local-scale structural connectivity as it relates to focal species through-passage frequency.

Two sites with moderate levels of through-passage frequency had an obvious “pinched” type of structural connectivity through the site (linking large forest blocks on either side of the road through the transportation structure), and other sites with low to moderate through-passage frequencies had a more “diffuse” type of structural connectivity. Considering these observations, we classified the local structural connectivity at each site by visually evident local-scale forest cover configuration into three categories (Figure 11 a-c). When mean through-passage frequencies were compared between these categories, frequencies were lowest for the sites in the “fragmented” category and greatest for sites in the “pinched” category, with intermediate values in the “diffuse category” (Figure 12), suggesting that local scale structural connectivity influences focal species through passage frequencies.

We were unable to attribute low through passage frequencies to the influence of other potentially important structural or site attributes at three of the 10 low-use sites (Sites 103-53, I91bE, and 114-22). All had good landscape context (with diffuse structural local-scale structural connectivity), and lacked structural characteristics that might discourage wildlife use. Site I-91bE (Figure 11b) is particularly interesting: no through-passages for focal species were recorded at this site. Yet it is paired with an adjacent monitored culvert (I-91bW) that received moderate amounts of use by bobcat, fisher, and small weasels. I-91bW and I-91bE are 5’-diameter pipe culverts that passes under the south and west-bound lanes (respectively) of I-91 in Sheffield. They convey the same stream under I-91, and are separated by an area of the I-91 median that is broad and semi-forested (See Appendix A).

Substrate type may also have some relationship to species-specific through-passage frequency patterns. For example, the “small weasel” group of mink, ermine, and long tailed weasel generally had higher mean through-passage frequencies at structures that featured rounded corrugated substrate found in metal pipe culverts (Figure 13), while deer, coyote, and bobcat had higher mean through-passage frequencies in structures with flat substrates. Fisher used both flat and corrugated pipe substrates.

Bobcat especially appeared to favor the use of concrete abutment shelves for moving through structures (Figure 14). Bobcats used these shelves exclusively at 2 sites where there was no other consistent dry movement surface under the structure. One of these shelves was quite narrow (6” wide), with bobcats precariously clinging to the edge of these shelves as they moved under the roadway. Few other obvious relationships between site or structure attributes and through-passage frequencies were evident. While many of site attributes have either been reported as important by other studies or intuitively would seem to be influential, (e.g Average Annual Daily Traffic), project data offered little in the way of broad support for any individual attribute.

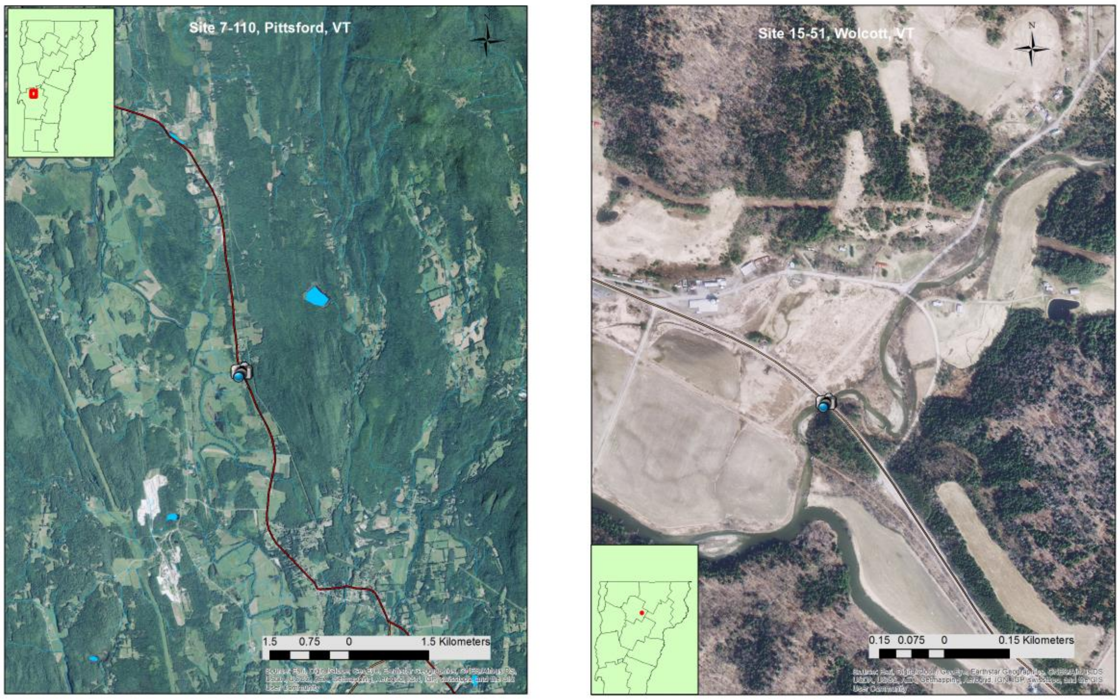

Figure 11a. Two examples of sites with “fragmented” (or discontinuous) local-scale structural connectivity of forested habitats. Large forest habitat blocks on either side of the road corridor are not structurally linked by smaller areas of forested habitat.

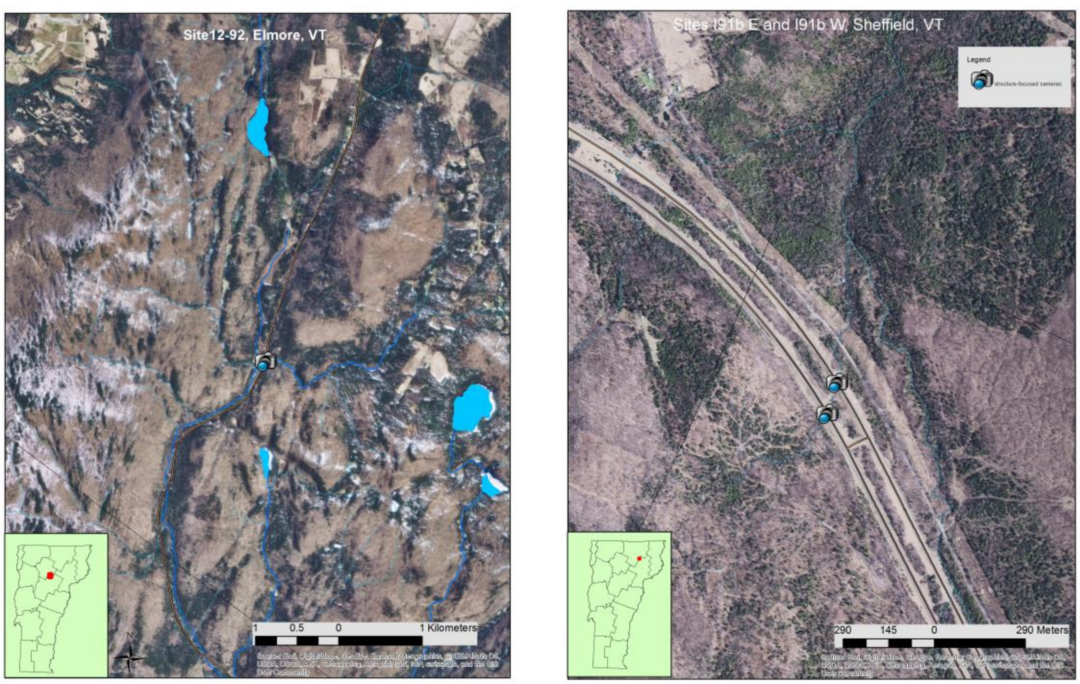

Figure 11b: Two examples of sites with “diffuse” local-scale structural connectivity of forested habitat. Road corridors directly bisect large areas of forested habitat.

Figure 11c. Two examples of sites with “pinched” local-scale forested habitat structural connectivity. Large forest habitat blocks on other side of the road are linked across road corridors by limited areas of continuous forested connecting habitat.

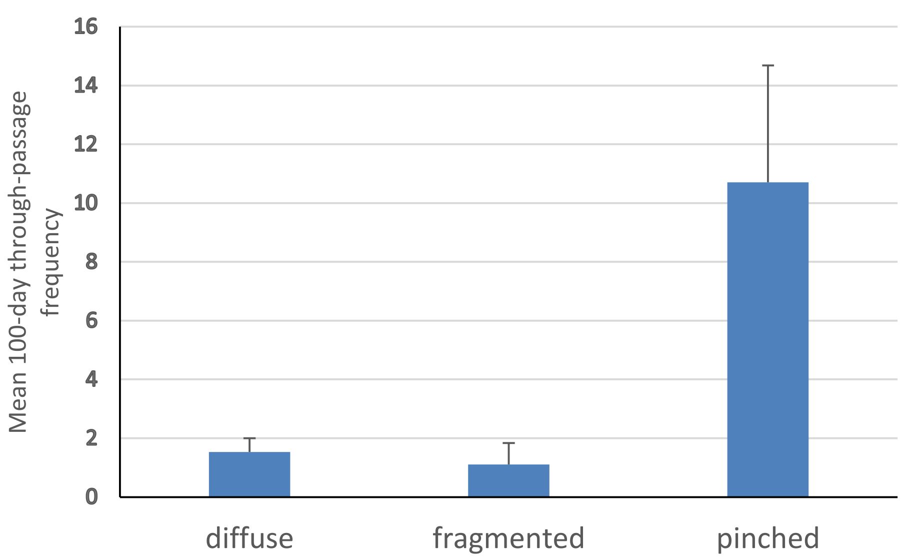

Figure 12. Mean (SE) focal species through-passage frequency for all sites by local-scale structural forest connectivity categories.

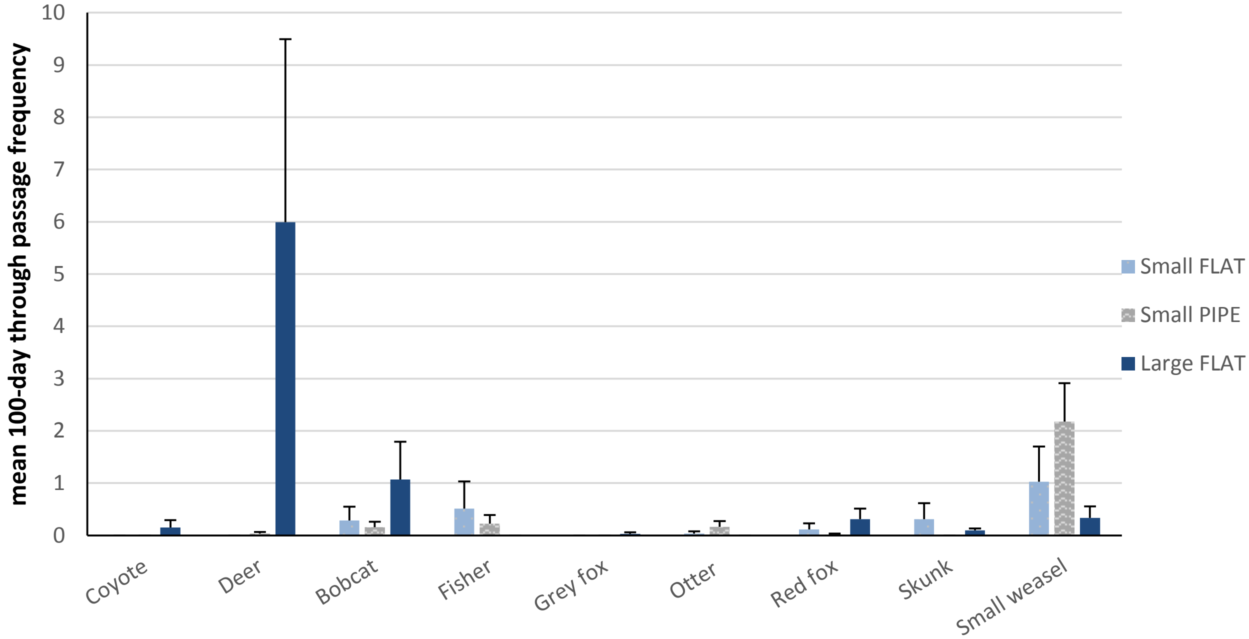

Figure 13. Mean through-passage frequency for each focal species by substrate type. Frequencies tended to be greater for mustelids (small weasels and fisher) in the “small structure flat substrate” and “small structure pipe substrate” categories. Deer frequencies were substantially larger in the “large structure flat substrate” category.

Figure 14. Bobcat using concrete abutment shelves for through-passage at Site 114-20 (left) and 4a-13 (right).

Finally, since we occasionally noticed photographs of tracks in snow that lacked a corresponding animal photograph, and that sites with redundant detection capabilities sometimes failed to record corresponding entrances and exits for each through-passage, it was apparent that game cameras were less than 100% effective at recording wildlife presence. Some of this was likely due to the variation in camera placement due the lack of an ideal camera mounting location at some sites. Accordingly, our data conservatively represents actual wildlife-structure interactions.

Discussion

Modified Movement Guild – Transportation Structure Size Class Framework

Our analysis suggests that the modified movement-guild/structure size class framework in Table 8 was consistent with observed patterns of focal species size class use, despite greater than anticipated between-site variation in through-passage frequencies. The framework therefore appears to be useful for making predictive generalizations about benefits for wide ranging species from proposed investments to make structures more suitable for through-passage use by replacing or retrofitting structures to wildlife-friendly specifications.

However, we are only able to attest to the usefulness of the movement guild-structure size class relationships in terms of the species that we actually detected using structures. For example, our modified framework (Table 8) was consistent with the prediction that medium/large size class structures are potentially able to be used by the AU movement guild, but with the qualification that this relationship remains hypothetical for moose, as we did not record any moose through-passages. Similar qualifications apply to the HOHMC movement guild, for which coyote was the only species with recorded through-passages. As noted earlier, coyote used only the largest structures in the medium/large size class for through-passage, which is consistent with the predictions for this guild in Shilling et al's (2012) framework. Finally, species in the other 2 movement guilds (MMSF and AHMF) were observed, as the framework in Table 8 would predict, using structures in all size classes for through-passage. However, through-passages of AHMF species are represented only by bobcat, as we lacked any through-passage data for bear and lynx. Overall, data for species that we lacked through-passage data on is needed to more completely substantiate the movement guild/size class framework in Table 8.

A lack of our ability to characterize moose and bear movement preferences are probably the most important limitations of our dataset. At sites with habitat-based cameras, moose and bear were detected at frequencies similar to red fox, which had a comparatively greater number of through-passages (Figure 15). While not definitive, the comparison with red fox data points toward the possibility that the structures at these sites were not well-suited for use by bear or moose. According to the Table 8 framework, bear, as part of the AHMF guild, is theoretically capable of using both small and medium/large size class structures, and moose (AU guild) is capable of using medium/large structures (which comprise 3 of the 6 structures at sites with habitat-focused cameras). Our habitat-focused cameras indicate that both bear and moose were present in habitat near monitored structures

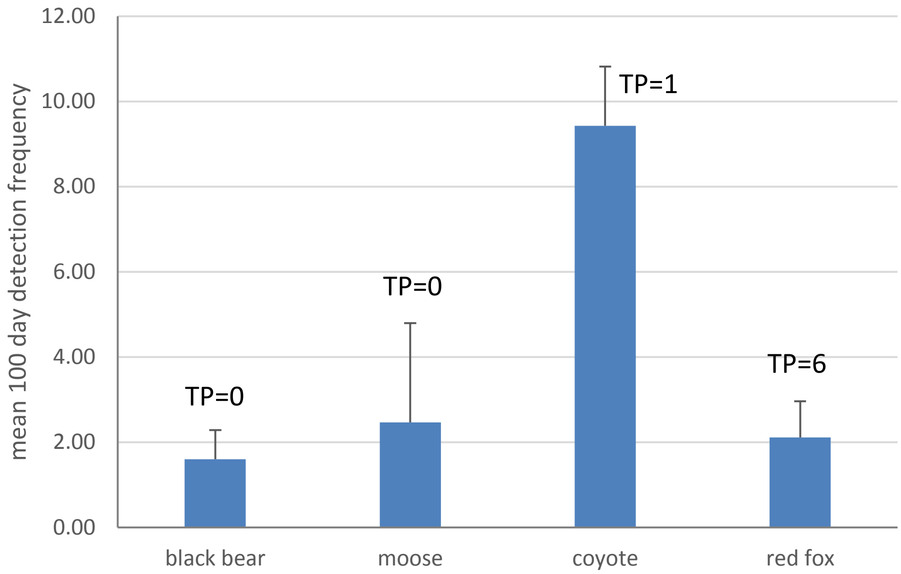

Figure 15. Mean (SE) 100-day detection frequency for habitat-focused cameras for bear, moose, coyote, and red fox. Data labels represent the number of through-passages recorded at these sites for each species. Note that detection frequencies for fox, moose, and bear are similar, yet a substantially higher number of through passages were recorded for red fox.

in sufficient enough numbers that we might have expected to document at least a few through-passages, yet no through-passages were recorded. It therefore seems possible that the types of transportation structures bear and moose may be willing to use in Vermont may be different than the relationships described in both Shilling et al's (2012) framework and our modified Table 8 framework.

Another structure monitoring effort on Route 9 in southern Vermont did detect three bear through-passages in 2016 through a large bridge span specifically designed for wildlife use (James Brady and Jaclyn Comeau, unpublished data). This project monitored 4 transportation structures with game cameras, and also collected evidence that bears were crossing over the traveled surface of Route 9 much more frequently than they were crossing under the road. Considering this data in addition to the lack of bear through-passages in our study, it is possible that bears in Vermont may avoid using all but very large and very open structures. If so, bears might be better placed in the HOHMC guild rather than the AHMF guild. Additional structure monitoring is needed to better categorize black bear in terms of its interactions with transportation structures with regards to movement guilds and structure size.

Results from this study, insights on black bear from the aforementioned Route 9 study, and, for species that lack through-passage data, categorizations from Shilling et al (2012), can be integrated to create a framework that both incorporates both the latest information on structure size/movement guild relationships and is transparent with respect to remaining data gaps and uncertainty (Table 9). This framework can be used as a starting place to guide future work on increasing the suitability of transportation structures for wildlife through-passage in Vermont.

Table 9. Modified movement guild-structure size class framework based on project results. Species that were documented using structures for through-passages in this study are underlined. Movement guild-size class relationships for species that were not recorded in our through-passage data remain hypothetical based on relationships specified in Shilling et al (2012). The uncertainty of bear movement guild assignment is represented by (?).

Size Class	Structure	Movement guild	species
Small underpass	pipe, box, and arch culverts; 3-6’ wide and < 8’ height	Moderate Mobility Small Fauna (MMSF)	small weasel, fox, otter, fisher
		Adaptive High Mobility Fauna (AHMF)	bear(?), lynx, bobcat
Medium underpass	Larger culverts between 5’ and 8’ width and >8’ height	Moderate Mobility Small Fauna (MMSF)	small weasel, fox, otter, fisher
		Adaptive High Mobility Fauna (AHMF)	bear(?), lynx, bobcat
		Adaptive Ungulates (AU)	deer, moose
Large underpass	bridge spans, large culverts > 10' wide, > 8’ high	Moderate Mobility Small Fauna (MMSF)	small weasel, fox, otter, fisher
		Adaptive High Mobility Fauna (AHMF)	bear(?), lynx, bobcat
		Adaptive Ungulates (AU)	deer, moose
		High Openness High Mobility Carnivores (HOHMC)	cougar, wolf, coyote, bear(?)

Since two of the monitored transportation structures had dimensions which did not fit within Shilling et al’s (2011) classification scheme for size classes, it is likely that other efforts to apply this framework will encounter similar difficulties. Transportation structure dimensions – especially with respect to bridge spans – are probably too variable for all structures to be classifiable within simple and straightforward size class dimension criteria. Accordingly, for this framework to have universal applicability, for anomalously dimensioned structures, there is a need to interpret size class assignment guidelines through the lens of specific dimensional thresholds that take into account the movement needs of species within a movement guild. For example, we classified site 73-5 as a large structure, even though it does not meet the height criteria for large structures. The height criteria for medium and large size classes is meant to capture structures that are high enough to accommodate deer and moose (Adaptive Ungulates, >8’ high). This structure had variable clearance between the most likely movement surface (a wide, dry, flat floodplain shelf) and the underside of the bridge of between 5’ -7’. Considering that the height was just below the 8’ threshold, and that the structure was by far the widest of all our sites (220’), we decided that it was more appropriate to place this bridge span into the medium/large size class rather than the small size class, as its openness would at least seem to encourage deer movement. This site was indeed used by deer, but not moose, which were also not detected by any of the four habitat-focused cameras deployed at the site.

Inferences on Focal Species Use of Bridges and Culverts in Vermont

Because there were more low-use sites in our study than we expected, it is reasonable to suspect that existing transportation structures on Vermont highways currently ill-serves cross-road corridor focal species movement needs. The primary objective of this study was to substantiate hypothetical relationships between movement guilds of wide-ranging wildlife species and transportation structure use based on structure size classes, so we used the best available knowledge about species-transportation structure interactions to select sites that appeared best suited for yielding wildlife through-passages data. As noted earlier, roughly 10% of structures on highways within SCI structural pathways met our site selection criteria, and a sizable proportion (43%) of the criteria-meeting sites were either not used at all (2 sites) or used minimally (8 sites). It is therefore likely that the number of well-located structures (with respect to forest habitat blocks) that are suited for focal species through-passages in terms of site and structural characteristics are in a distinct minority.

Site characteristics and focal species through-passage

While our results did suggest the importance of local-scale structural connectivity for explaining some of the variance in site through-passage data, this relationship should be more robustly assessed via more quantitative methods. For example, conducting a series of small-scale connectivity modeling exercises at each site could quantify structural connectivity in a way that could be quantifiably related to through-passage frequency data. This would yield more definitive than we were able to generate, as our analysis simply relied on subjective visual assessment of forest cover at each site from orthophotos. Even lacking such an effort, future studies needing to select sites that are most likely to be used by wildlife can probably benefit from avoiding sites with fragmented local structural connectivity, and to the extent available, use sites with pinched local structural connectivity. Moreover, conservation investments in transportation infrastructure intended to better serve the need for under-road wildlife movement are probably best made at sites where local-scale structural connectivity is "pinched" in character, or can be restored from a "fragmented" to a "pinched" configuration.

Structure characteristics and focal species through-passage

Shilling et al's (2012) movement guild-structure size class framework was derived from species/structure use relationships observed from studies conducted in the Western US. The fluvial channels that transportation structures accommodate in the west generally have a different hydrology than those found in Vermont: smaller-order western streams are generally more intermittent and less consistently inundated, as structures that convey intermittent streams in watershed with a drier climate generally have more dry surfaces per structure area for wildlife to move over. This is an important factor in assessing the suitability of a structures in Vermont for wildlife movement, as our photo data indicates that most species, with the exceptions of deer, raccoon, and aquatic species such as otter, muskrat, and beaver, will generally avoid walking in water.

Interestingly, two of our sites had anomalous hydrology for Vermont streams. Typically, streams in Vermont with upstream watershed sizes of > 0.5 square miles are almost all perennial. Sites 113-33 in Ira and 30-84 in Poultney however are exceptional outliers: these sites hosted large size-class bridge spans and crossed large channels that were perennially dry. These sites had upstream watersheds of 2.9

and 5.3 square miles and bankfull channel widths of 18.1’ and 31.5’, respectively. In terms of through-passages, Site 30-84 had by far the highest frequency of focal species through-passages of all our sites, and Site 133-13 had the 4th highest through-passage frequency, suggesting the importance of dry surface availability for wildlife use. Focal species moving under these structure were all moving in the dry river channels.

For streams and rivers with hydrology more typical for Vermont, the design attributes of the structure itself or the size of the structure with respect to the size of the stream it conveys influences the availability of dry movement surfaces for terrestrial wildlife, thereby hypothetically making structures more or less suitable for use by wildlife for cross-road movement. Results from some of our sites were consistent with this relationship: the predominantly inundated sites with concrete abutment shelves (Figure 7) provided dry movement surfaces that were used frequently by bobcats. Pipe culverts that carried small streams relative to structure width often were dry or nearly dry at low flows, conditions that provided dry surfaces for the movement of fisher and weasels, and to a lesser degree, bobcats. Flat-bottomed box culverts with small upstream watersheds typically hosted, during low flow periods, a trickling type of sheet flow through the structure that allowed for the movement of mustelids, and even, on one occasion, a bobcat, but these structures still featured substrate that, though shallow, was predominantly wet. We had only one site with a “V” bottomed box culvert (Site 103-53). Site 103-53 typically featured a great deal of dry concrete movement surface during low flows. It did get used by a variety of focal species (bobcat, deer, and small weasel), but at very low frequencies, perhaps because of the length of the structure (280’).

Many larger bridges in Vermont have large areas of dry streambank underneath, but these banks typically consist of large rip-rap, creating movement surfaces that may discourage use by larger mammals. Lack of through-passage at Site 15-51 in this study may be attributable in part (in addition to possible effects of fragmented local scale structural connectivity) to this factor.

Notably, VTrans has developed standard practice specifications for grubbing over rip-rap to create a more even walking surface for wildlife when bridge spans are rebuilt. Wildlife have already been documented to be taking advantage of such structural design changes to walk under highways in Vermont on the US 2/I-89 crossing of the Little River in Waterbury VT (Jens Hilke and James Brady, unpublished data).

Suffice it to say that the relationship between structure characteristics and wildlife movement is complex and multifaceted – too much so to be adequately substantiated by data collected in this project. Our study sites had unique combinations of site and structural characteristics that confounded our attempts to isolate the influence of any one characteristic on through-passage data, as interacting multiple factors were likely in play at a number of sites.

Additional research designed to assess a variety of bridge design attributes (concrete ledges, grubbed riprap or other consistently dry movement surfaces during low flows) while controlling for site-based attributes such as small scale structural connectivity would likely yield more data on wildlife-through passages that would more completely describe relationships between transportation structure design attributes, size class, and species use/movement guild use patterns.

Conclusions

Our analysis of wildlife through-passage frequencies first indicated the need to modify Shilling et al's (2012) movement guild-based framework by moving coyote to the HOHMC movement guild from the AHMF guild. Our subsequent analysis of the relationship between modified movement guild species groupings and observed focal species use of transportation structures for through-passage was consistent with predicted patterns of use between structure size classes and movement guilds. Therefore, we feel confident about recommending the use of this framework (Table 9) for informing efforts to increase the permeability of highways for wide-ranging wildlife in Vermont, as long as interpreted with due consideration of the limitations of our analysis. Interpretive limitations specifically apply to the focal species that were not recorded using transportation structures for moving under roadways (bear, moose, lynx, and extirpated cougar and wolf). Because of the absence of data from these species, three movement guilds were represented by through-passage data from only one species (deer in the AU guild, bobcat in the AHMF guild, and coyote in the HOHMC guild), limiting our ability to generalize about the potential usability of a given structure by all species within any one of these guilds.

Since we made every effort to select study sites that were best suited for use by focal species for moving under highways, there was a surprisingly large amount of between-site variance in through-passage data: 10 of 23 sites yielded surprisingly low through-passage frequencies of focal species, suggesting that the existing set of transportation structures does not serve the cross-road movement needs of focal species particularly well. Also, the results from habitat-focused cameras at six sites indicated that the near or total lack of through passage data at a site, whether it was in terms of all focal species, or species that were not detected using transportation structures, (bear, moose, and coyote) was due to factors other than the relative absence of these species in nearby habitats.

While there were many factors that may have contributed to the lack of through-passages at low-use sites, our analysis provided broad support for only two: the character and configuration of continuous forested structural connectivity through a site at the location of the bridge or culvert, and the presence of hunting dog pens at nearby residences. Since focal species through-passage frequencies were comparatively large for sites where the structural connectivity of forest habitat that linked adjoining forest blocks was "pinched", local-scale structural connectivity around a transportation structure appears as an important factor in assessing the existing or potential value of a given transportation structure for wildlife through-passage use.

The presence of consistently dry movement surfaces that offer even footing inside of a structure also appeared to be valuable for encouraging focal species use. Because the presence or absence of such movement surfaces are generally a function of the design characteristics of a given structure, additional work is needed specifically designed to assess a range of structural characteristics of bridges and culverts (concrete shelves, ration of structure width to bankfull width, etc.) on patterns of wildlife use.

This study provides valuable information that can be used to help target locations for and specify the benefits of investments in transportation infrastructure aimed at making bridges and culverts more likely to be used by wildlife for crossing under highways. Our results generally support the use of the modified movement guild-structure size class framework in Table 9 for identifying the sets of species that would potentially benefit form efforts to improve the usability of transportation structures by wildlife. This framework, though not yet fully substantiated, appears useful for identifying species that would benefit from efforts to re-construct or retrofit culverts in ways that encourage wildlife through-passage.

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http://www.statefarm.com/aboutus/_pressreleases/2011/october/3/us-deer-collisions-fall-map.pdf
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http://www.vtfishandwildlife.com/library/factsheets/Hunting_and_Trapping/big_game/Moose_fact_sheet.pdf

Appendix A: Site Information and Maps

Site 103-53

Downstream

Upstream


Downstream camera (red circle)


Upstream camera (red circle)

Site/Structure Characteristics

Structure type	box culvert
Structure width	15’
Height	10’
Length	280’
Size class	Medium/Large
Bankfull width/structure width ratio	0.8
Road elevation above streambank	60’
Road AADT	5000
Local structural connectivity	diffuse
Distance to nearest forest block N or E	421m
Distance to nearest forest block S or W	94m

Site 122-24


Site 122-24, Glover, VT
Legend
habitat-focused camera
structure-focused cameras
200
100
0
200 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream

Upstream


Upstream camera


Downstream camera

Site/Structure Characteristics

Structure type	Box culvert
Structure width	4’
Height	4’
Length	36’
Size class	small
Bankfull width/structure width ratio	0.6
Road elevation above movement surface	9.5
Road AADT	520
Local structural connectivity	pinched
Distance to nearest forest block N or E	25m
Distance to nearest forest block S or W	15m

Site 73-5


Site 73-5, Sudbury, VT
Legend
habitat-focused camera
structure-focused cameras
220
110
0
220 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream, floodplain shelf

Downstream, left descending bank

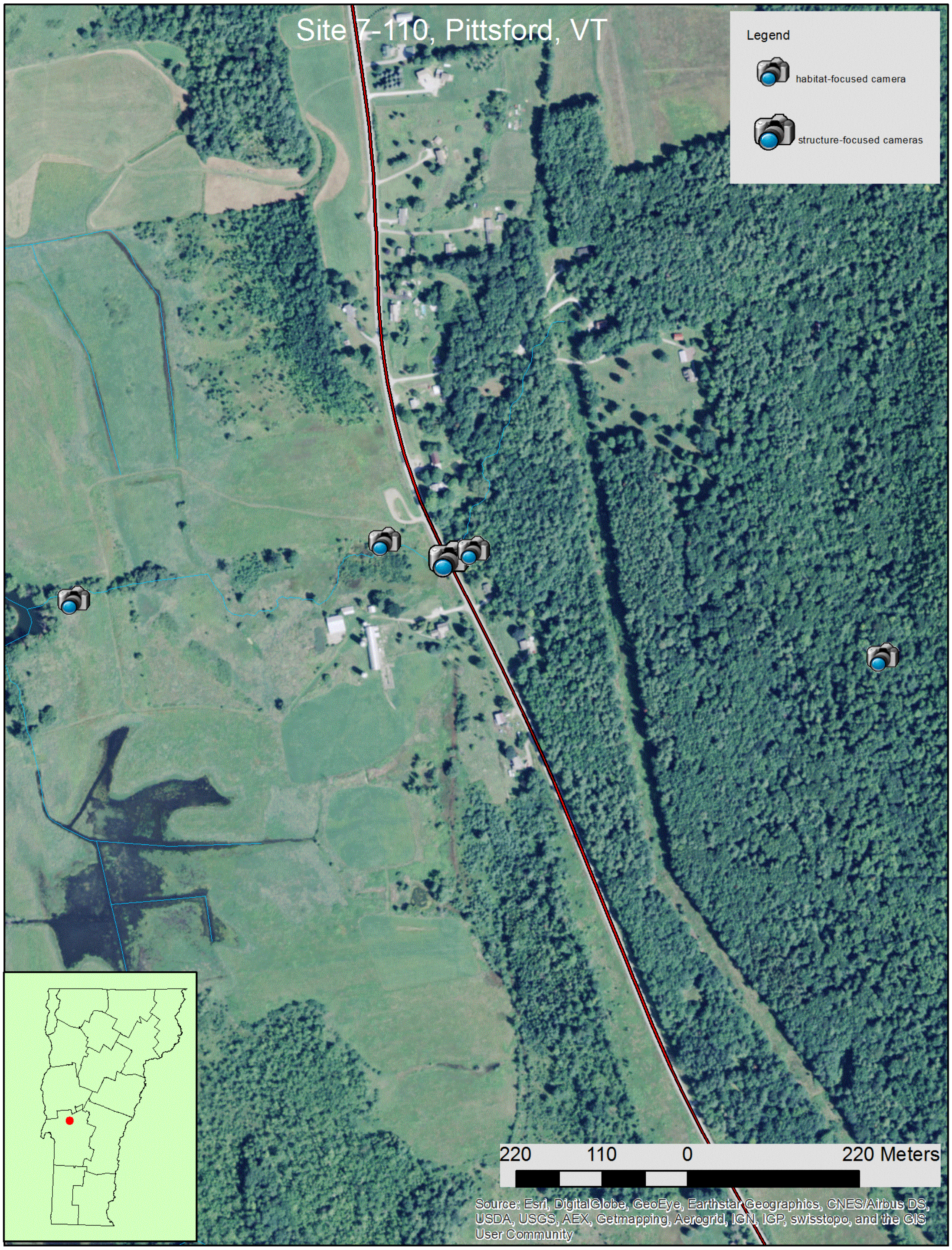
Downstream, right descending bank abutment

Upstream, right descending bank abutment

Site/Structure Characteristics

Structure type	bridge span
Structure width	235’
Height	5 – 7’
Length	32’
Size class	Medium/large
Bankfull width/structure width ratio	1.2
Road elevation above streambank	9.0’
Road AADT	1000
Local structural connectivity	diffuse
Distance to nearest forest block N or E	445m
Distance to nearest forest block S or W	306m

Site 7-110


Site 7-110, Pittsford, VT
Legend
habitat-focused camera
structure-focused cameras
220 110 0 220 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream

Upstream


Downstream camera


Upstream camera

Site/Structure Characteristics

Structure type	box culvert
Structure width	5’
Height	6’
Length	60.2’
Size class	small
Bankfull width/structure width ratio	0.6
Road elevation above streambank	15.8’
Road AADT	7200
Local structural connectivity	fragmented
Distance to nearest forest block N or E	50m
Distance to nearest forest block S or W	1900m

Site 15-51


Site 15-51, Wolcott, VT
Legend
habitat-focused camera
structure-focused cameras
180
90
0
180 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Right descending bank

Right descending bank

Left descending bank

Left descending bank


Left descending bank camera

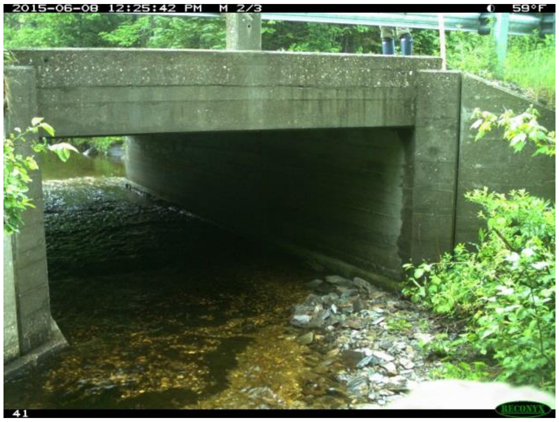

Bridge pier and right descending bank cameras

Site/Structure Characteristics

Structure type	bridge span
Structure width	128
Height	35
Length	26.4
Size class	Medium/large
Bankfull width/structure width ratio	1.9
Road elevation above movement surface	17
Road AADT	4600
Local structural connectivity	fragmented
Distance to nearest forest block N or E	427m
Distance to nearest forest block S or W	265m

Site 12-92


Site 12-92, Elmore, VT
Legend
habitat-focused camera
structure-focused cameras
280 140 0 280 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Upstream

Downstream


Upstream camera


Downstream camera

Site/Structure Characteristics

Structure type	box culvert
Structure width	11’
Height	5.5’
Length	30’
Size class	small
Bankfull width/structure width ratio	0.5
Road elevation above movement surface	6’
Road AADT	940
Local structural connectivity	diffuse
Distance to nearest forest block N or E	15m
Distance to nearest forest block S or W	15m

Site 2-90


Site 2-90, Cabot, VT
Legend
habitat-focused camera
structure-focused cameras
220 110 0 220 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream

Upstream

Site/Structure Characteristics

Structure type	Pipe with flat concrete bottom
Structure width	6
Height	6.25
Length	62
Size class	Small
Bankfull width/structure width ratio	1.2
Road elevation above streambank	15
Road AADT	3200
Local structural connectivity	fragmented
Distance to nearest forest block N or E	200
Distance to nearest forest block S or W	399

Site 4-12-7


Site 4-12-7, Ira, VT
Legend
structure-focused cameras
220 110 0 220 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream

Upstream


Downstream camera position


Upstream camera position

Site/Structure Characteristics

Structure type	corrugated pipe
Structure width	6’
Height	6’
Length	311’ (one 157’ and one 144’ pipe with break in median)
Size class	small
Bankfull width/structure width ratio	0.6
Road elevation above streambank	12’
Road AADT	13000
Local structural connectivity	pinched
Distance to nearest forest block N or E	15m
Distance to nearest forest block S or W	524m

Site 4a-13


Site 4a-13, Ira, VT
Legend
structure-focused cameras
220 110 0 220 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream

Upstream left descending abutment

Downstream right descending abutment


Downstream camera (off of photo to left)


Upstream cameras

Site/Structure Characteristics

Structure type	bridge span
Structure width	13.5’
Height	9’
Length	33.5’
Size class	Medium/large
Bankfull width/structure width ratio	0.6
Road elevation above streambank	10.5’
Local structural connectivity	pinched
Road AADT	1700
Distance to nearest forest block N or E	674
Distance to nearest forest block S or W	64

Site 12-83

Site 12-83, Worcester, VT
Legend
structure-focused cameras
220 110 0 220 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Left descending abutment

Right descending abutment

Camera locations

Site/Structure Characteristics

Structure type	bridge span
Structure width	29’
Height	12’
Length	31’
Size class	Medium/large
Bankfull width/structure width ratio	1.2
Road elevation above streambank	10.6’
Local structural connectivity	pinched
Road AADT	940
Distance to nearest forest block N or E	34m
Distance to nearest forest block S or W	41m

Site 14-102


Site 14-102, Hardwick, VT
Legend
structure-focused cameras
140
70
0
140 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Upstream

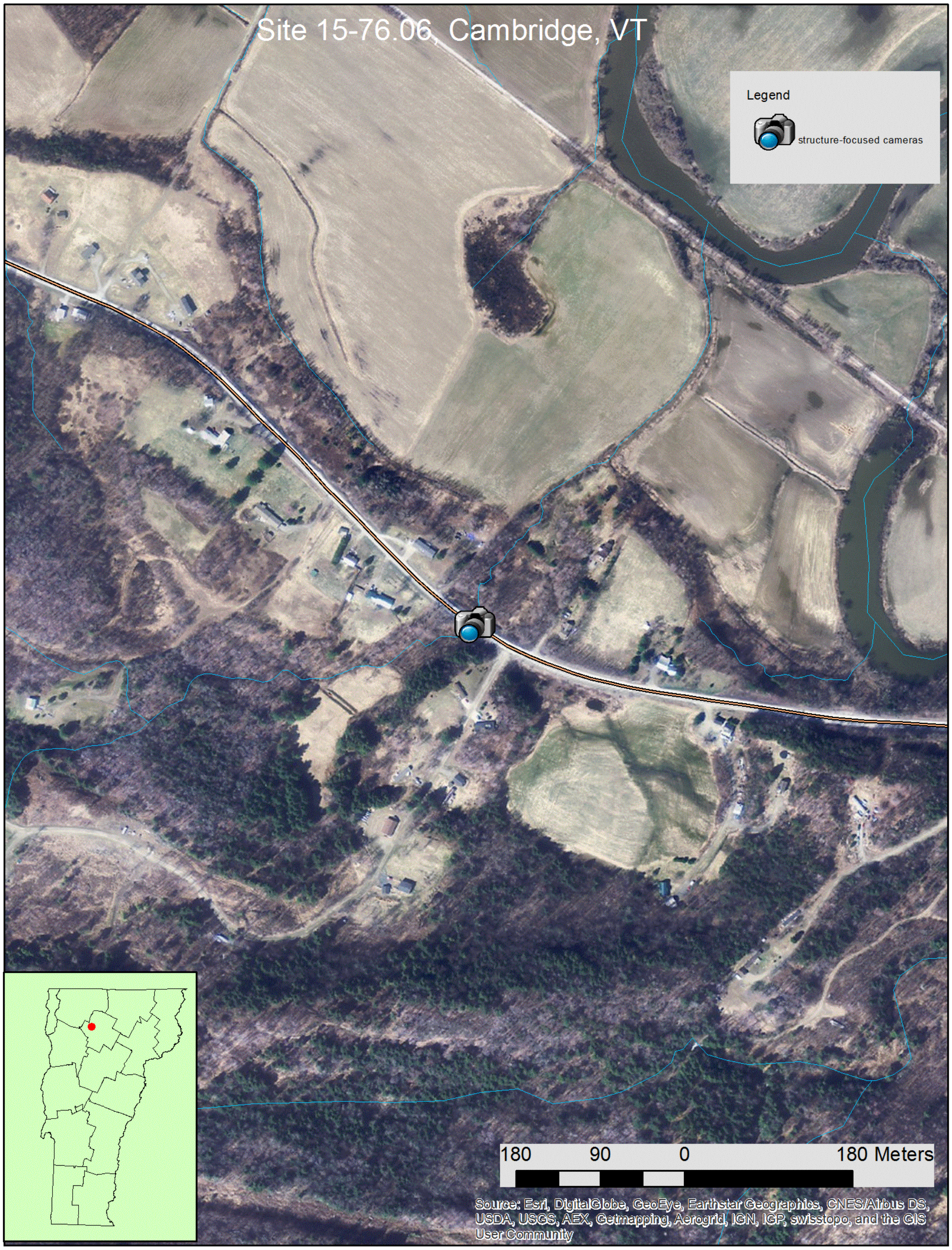
Downstream


Upstream Camera

Site/Structure Characteristics

Structure type	arch culvert
Structure width	5’
Height	3’
Length	46’
Size class	Small
Bankfull width/structure width ratio	0.5
Road elevation above streambank	1’
Local structural connectivity	diffuse
Road AADT	1200
Distance to nearest forest block N or E	9400
Distance to nearest forest block S or W	15

Site 15-76.06



Site 15-76.06, Cambridge, VT
Legend
structure-focused cameras
180 90 0 180 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Upstream

Downstream


Downstream camera


Upstream camera (on left out of photo)

Site /Structure Characteristics

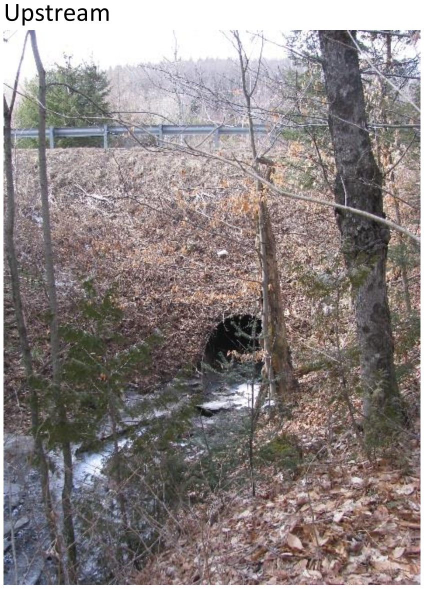
Structure type	box culvert
Structure width	4’
Height	5’
Length	46’
Size class	Small
Bankfull width/structure width ratio	0.4
Road elevation above streambank	18’
Local structural connectivity	fragmented
Road AADT	6000
Distance to nearest forest block N or E	874m
Distance to nearest forest block S or W	193m

Site 16-13


Site 16-13, Glover, VT
Legend
structure-focused cameras
120
60
0
120 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Upstream

Downstream


Upstream (camera off to left)


Downstream camera

Structure/Site Characteristics

Structure type	corrugated pipe culvert
Structure width	6’
Height	6’
Length	100’
Size class	Small
Bankfull width/structure width ratio	0.9
Road elevation above streambank	22’
Local structural connectivity	pinched
Road AADT	1200
Distance to nearest forest block N or E	28m
Distance to nearest forest block S or W	28m

Site 16-14

Site 16-14, Glover, VT
Legend
structure-focused cameras
180 90 0 180 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Upstream

Downstream


Upstream camera


Downstream camera

Site/Structure Characteristics

Structure type	box culvert
Structure width	6.5’
Height	4’
Length	62’
Size class	Small
Bankfull width/structure width ratio	1.2
Road elevation above streambank	14.5’
Local structural connectivity	pinched
Road AADT	1200
Distance to nearest forest block N or E	184m
Distance to nearest forest block S or W	15m

Site 30-84

Site 30-84, Poultney, VT
Legend
structure-focused cameras
180 90 0 180 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream left descending abutment

Upstream left descending abutment

Upstream right descending abutment

Downstream right descending abutment

Site/Structure Characteristics

Structure type	bridge span
Structure width	23.5’
Height	8’
Length	33.5’
Size class	Medium/large
Bankfull width/structure width ratio	0.7
Road elevation above streambank	10’
Local structural connectivity	pinched
Road AADT	1700
Distance to nearest forest block N or E	121m
Distance to nearest forest block S or W	1300m

Site 114-20

Site 114-20, Brighton, VT
Legend
structure-focused cameras
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream left descending abutment, camera

Downstream right descending abutment, camera

Upstream right descending abutment, camera

Upstream left descending abutment, camera

Site Characteristics

Structure type	bridge span
Structure width	19.5
Height	5’
Length	22’
Size class	Small
Bankfull width/structure width ratio	0.6
Road elevation above streambank	7’
Local structural connectivity	diffuse
Road AADT	1000
Distance to nearest forest block N or E	15m
Distance to nearest forest block S or W	15m

Site 114-22

Site 114-22, Brighton, VT
Legend
structure-focused cameras
125 62.5 0 125 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream

Upstream


Downstream camera


Upstream camera

Site/Structure Characteristics

Structure type	box culvert
Structure width	7'
Height	6'
Length	62'
Size class	Small
Bankfull width/structure width ratio	0.7
Road elevation above streambank	16'
Local structural connectivity	diffuse
Road AADT	1000
Distance to nearest forest block N or E	73m
Distance to nearest forest block S or W	15m

Site 133-13


Site 133-13, Ira, VT
N
0.1 0.05 0 0.1 Kilometers
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream left descending abutment and camera

Upstream right descending abutment and camera

Downstream right descending abutment and camera

Upstream left descending abutment and camera

Site/Structure Characteristics

Structure type	bridge span
Structure width	22’
Height	7.8’
Length	29.5’
Size class	Medium/large
Bankfull width/structure width ratio	1.2
Road elevation above streambank	10’
Local structural connectivity	pinched
Road AADT	900
Distance to nearest forest block N or E	135m
Distance to nearest forest block S or W	941m

I91 101-2s


Site I-91 101-2s
Legend
structure-focused cameras
140
70
0
140 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Upstream

Downstream


Upstream camera


Downstream camera

Site/Structure Characteristics

Structure type	Corrugated pipe
Structure width	7’
Height	7’
Length	38’
Size class	Small
Bankfull width/structure width ratio	0.8
Road elevation above streambank	19’
Local structural connectivity	diffuse
Road AADT	4600
Distance to nearest forest block N or E	75m
Distance to nearest forest block S or W	15m

I91 101-3s

SIte I91-101-3s, Sheffield, VT
Legend
structure-focused cameras
180 90 0 180 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Upstream

Downstream


Upstream camera


Downstream camera

Site/Structure Characteristics

Structure type	Corrugated pipe
Structure width	6’
Height	6’
Length	104’
Size class	Small
Bankfull width/structure width ratio	0.4
Road elevation above streambank	15’
Local structural connectivity	diffuse
Road AADT	4600
Distance to nearest forest block N or E	160m
Distance to nearest forest block S or W	15m

I91a


Site I91a, Sheffield, VT
Legend
structure-focused cameras
180 90 0 180 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Downstream

Upstream


Downstream camera


Upstream camera

Site/Structure Characteristics

Structure type	Corrugated pipe
Structure width	5’
Height	5’
Length	190’
Size class	Small
Bankfull width/structure width ratio	0.8
Road elevation above streambank	43’
Local structural connectivity	diffuse
Road AADT	4600
Distance to nearest forest block N or E	133m
Distance to nearest forest block S or W	102m

Site I91bE and I-91bW

I91bW upstream

I91bW downstream

I91bE upstream

I91bE downstream

I91bW upstream camera

I91bW downstream camera

I91bE upstream camera

I91bE downstream camera

Site/Structure Characteristics

I91bW:

Structure type	Corrugated pipe
Structure width	5’
Height	5’
Length	180
Size class	Small
Bankfull width/structure width ratio	0.8
Road elevation above streambank	25’
Local structural connectivity	diffuse
Road AADT	4600
Distance to nearest forest block N or E	65m
Distance to nearest forest block S or W	15m

I91bE:

Structure type	Corrugated pipe
Structure width	5’
Height	5’
Length	228’
Size class	Small
Bankfull width/structure width ratio	0.8
Road elevation above streambank	38’
Local structural connectivity	diffuse
Road AADT	4600
Distance to nearest forest block N or E	15m
Distance to nearest forest block S or W	65m

Guard rails on road

Appendix B – Select game camera photos

Bobcat at 4a-13 in Ira crossing on a narrow concrete shelf

A mink (suspected) crossing under 30-84 in Poultney.

Bobcat at 4a-13 in Ira crossing on a narrow concrete shelf

A deer and fawn crossing under US 7 in Pittsford at Site 7-110.

A deer crossing under 4a-13 in Ira during high water.

Coyote crossing under 133-13 in Ira

Bobcat crossing under 133-13 in Ira

Deer crossing under 30-84 in Poultney

Collecting Photos from 12-92 in Elmore, June 2015

A fisher moving under 30-84 in Poultney.

Bobcat crossing under 133-13 in Ira.

Bobcats crossing under 114-20 in Newark

Bear south of 15-51 in Wolcott

Otter crossing under 114-22 in Brighton

Bobcat entering 103-53 in Shrewsbury

Bobcat exiting I91bW in Sheffield

Fisher exiting 16-14 in Glover

Domestic cat encounters raccoon at 16-14 in Glover

Fisher exiting I91a in Sheffield

Moose south of 15-51 in Wolcott

Moose west of 12-92 in Elmore

Bobcat north of 73-5 in Sudbury

Bear and cub east of 12-92 in Elmore

Fisher south of 122-24 in Glover