Reducing Wildlife Mortality on Roads in Vermont: Determining Relationships Between Structure Attributes and Wildlife Movement Frequency Through Bridges and Culverts to Improve Rela...

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VERMONT
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Reducing Wildlife Mortality on Roads in Vermont: Determining Relationships Between Structure Attributes and Wildlife Movement Frequency Through Bridges and Culverts to Improve Related Conservation Investments

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The Nature Conservancy – Vermont Chapter

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16. Abstract

This project gathered and analyzed game-camera data on the frequency of wildlife movement through bridges and culverts in Vermont to generate results-based recommendations for improving the permeability of highways in Vermont for wildlife. By better understanding the characteristics of transportation structures that wildlife are more likely to use for moving under roadways, state resource and transportation agencies will have a greater ability to manage road corridors in ways that can reduce the inherent habitat-fragmenting effects of the road network in Vermont. Specifically, this project assessed the effects of different types of transportation structure designs on usability by wildlife for under-road movement (through-passage). 1,347 through-passages of a set of 13 focal species were recorded at 26 culverts and bridges on busy road corridors in 2017 and 2018. A structure design classification system was developed that provided explicit links between structure design types and a variety of movement surface types used by wildlife for through-passage. Game camera data substantiated the ability of several structure design types to offer specific kinds of wildlife-usable dry movement surfaces, and variation in through-passage data among different design types illustrated the influence of interactions between structure design characteristics and movement surface availability on the frequency of wildlife use. In particular, bridge spans offered the greatest number of movement surface types, generally supported the highest through-passage frequencies, and was used by the most wildlife species. Pipe and squash pipe culverts offered more limited through-passage suitability for wildlife. We were not able to assess modern embedded box culvert designs due to enduring on-site habitat disturbance from construction activities, but our data from other structures suggest that they will prove valuable for wildlife through-passage once vegetation in construction footprints matures. Older flat bottom box culvert designs performed poorly in terms of wildlife use. Our results also suggest a relationship between factors relating to stream hydrology and movement surface type/availability in all structure design types intended to feature natural stream bottoms, where streamflow and deposition/erosion governs the formation and maintenance of movement surfaces of varying levels of suitability for wildlife movement. Project results also confirmed that the modified Movement Guild framework presented in Marangelo and Farrell (2016) that relates potential species use to culvert/ridge size accurately reflected observed patterns of wildlife structure use, except for bears. A small number of bear through-passages in this study suggests that bears should no longer be considered among the species likely to use small size class culverts.

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1. Project Overview

The rationale for this project is rooted in the evolving field of road ecology, which has thoroughly demonstrated that 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 impairs a conservation value of increasing importance: the connectedness of forested habitats for wide-ranging terrestrial throughout and beyond Vermont. This project represents perhaps the most extensive research effort to develop road corridor management options to encourage the movement of wildlife underneath through bridges and culverts in the northeastern US to date.

This study builds on the preceding phase of this project (Marangelo and Farrell 2016), which generated crucial insights about wildlife use of transportation structures in Vermont for through-passage. Specifically, we:

1) Set up a camera monitoring system to document relationships between wildlife use frequency and specific design attributes of transportation structures found among the types of culverts that wildlife has been shown to use to move under roadways from Marangelo and Farrell (2016).
2) Interpret project results in a way that can inform, influence, and improve regional decision-making and management practices in road corridors to decrease the habitat-fragmenting effects of road corridors for wildlife.

For example, if a 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 informing structure replacement or retrofit in ways that will provide greater opportunity for the movement of wildlife under the roadway. Similarly, where roads form near-impermeable wildlife movement barriers between 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 benefits for individual wildlife species or groups of species.

The importance of this issue is augmented by the increasingly urgent conservation need to improve the functionality of a regionally connected network of 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, better enabling movement-related adaptation needs that may arise in response to increasing rates of habitat change

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[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.*

driven by climate change. Statewide highway infrastructure that is managed to increase wildlife permeability in key areas, thereby better connecting habitats otherwise separated by road corridors, is an important part of creating and maintaining a habitat network that links regionally significant habitat areas (such as between the Green and Adirondack Mountains).

The first phase of this study (Marangelo and Farrell 2016) 1) substantiated a Passage Assessment System Framework modified from Shilling et al (2012) for identifying potential species use based on structure size characteristics; 2) found that site characteristics such as structural connectivity of forested habitats that links habitat on either side of the road through a structure appeared to have a substantial influence on the frequency of structure use by wildlife; and 3) hypothesized that a good deal of otherwise unexplained variation in through-passage data may be related to the influences of transportation structure characteristics on wildlife through-passage frequency, and these characteristics are linked to specific structure designs.

This study builds on the results of the preceding study by primarily addressing questions related to the third Phase 1 study outcome. Using our refined understanding of the effects of site characteristics on wildlife structure use from Marangelo and Farrell (2016), for this study we sought to select a range of different structure designs at structure sites that were most likely to be used by wildlife for through-passage. Resulting through-passage data from these sites would is then used to better characterize the effects of different structure design types on wildlife use for under-road movement.

2. Methods

2.1. Site Selection and Game Camera Installation

We identified 26 bridges and culverts to collect data on wildlife *through-passage* with game cameras (Table 1; Figures 1, 2, 3, and 4)*,* where a through-passage is the movement of an animal under a roadway through a culvert or bridge. Cameras were setup at most sites in April 2016, with a small number of sites being set up later that summer. Camera data collection concluded in December 2018.

To select study sites, we examined all bridges and culverts on state and interstate highways that intersect a spatial data layer that identify a habitat network connecting large forested habitat blocks in Vermont (Vermont Agency of Natural Resources, 2016). Our site selection process was based on 1) “fatal flaws” screening criteria from the Passage Assessment System (PASS; Kintsch and Cramer 2011) that evaluates culverts for potential usability by at least one “movement guild” of species from the modified PASS framework from Marangelo and Farrell (2016); 2) insights on wildlife/transportation structure use generated by Marangelo and Farrell (2016), which suggested that a suite of structure and site characteristics influenced the frequency of wildlife transportation structure use: the availability of dry movement surfaces within a structure; movement surface composition; and the structural connectivity of forested habitat through a transportation structure site linking larger forest blocks on either side of the roadway (we screened out structures that featured discontinuous structural connectivity site characteristics Marangelo and Farrell (2016)).

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

- 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
- 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?)
- Proximity and type of development to structure

We then developed a list of structure design types that we believed offered different kinds of movement surface availability (Table 2; more detail in Appendix A), and attempted to achieve, as much as possible, equal representation of each design type in our set of sites selected for this study.

Table 1. Twenty-six camera sites for monitoring wildlife use of transportation structures with structure size class and design type. More details are found in Appendix A

Structure	**Road**	**Town**	**Size class**	**Design type**
4-42	US 4	Bridgewater	med/large	*span*
7-19-5	US 7	Sunderland	small	*squash pipe*
7-23-8	US 7	Manchester	small	*pipe culvert*
9-17	VT 9	Woodford	small	*pipe culvert*
100-118	VT 100	Killington	med/lg	*new precast box culvert**
100-47	VT 100	Wilmington	med/lg	*new precast box culvert**
100-78	VT 100	Jamacia	med/lg	*span**
100a-8	VT 100a	Plymouth	med/lg	*span**
113-15	VT 113	Vershire	small	*squash pipe*
113-19	VT 113	Vershire	med/lg	*span*
122-24	VT 122	Glover	small	*old box culvert*
125-19	VT 125	Ripton	med/lg	*new precast box culvert**
12a-10	VT 12a	Braintree	med/lg	*span*
133-13	VT 133	Ira	med/lg	*span with footing shelf*
155-6	VT 155	Mt Holly	small	*pipe culvert*
16-13	VT 16	Glover	small	*pipe culvert*
17-24	VT 17	Starksboro	med/lg	*arch culvert*
17-32	VT 17	Waitsfield	med/lg	*span*
17-36	VT 17	Waitsfield	med/lg	*span*
30-22	VT 30	West Townshend	small	*old box culvert*
30-47	VT 30	Winhall	small	*new precast box culvert**
9-25a	VT 9	Searsburg	med/lg	*span*
9-25b	VT 9	Searsburg	med/lg	*span*
I91-17-2	I 91	Putney	med/lg	*"V" bottom box culvert*
I91a	I 91	Sheffield	small	*pipe culvert*
Union Street	Union Street	Brandon	med/lg	*span*

* new post-Irene structure

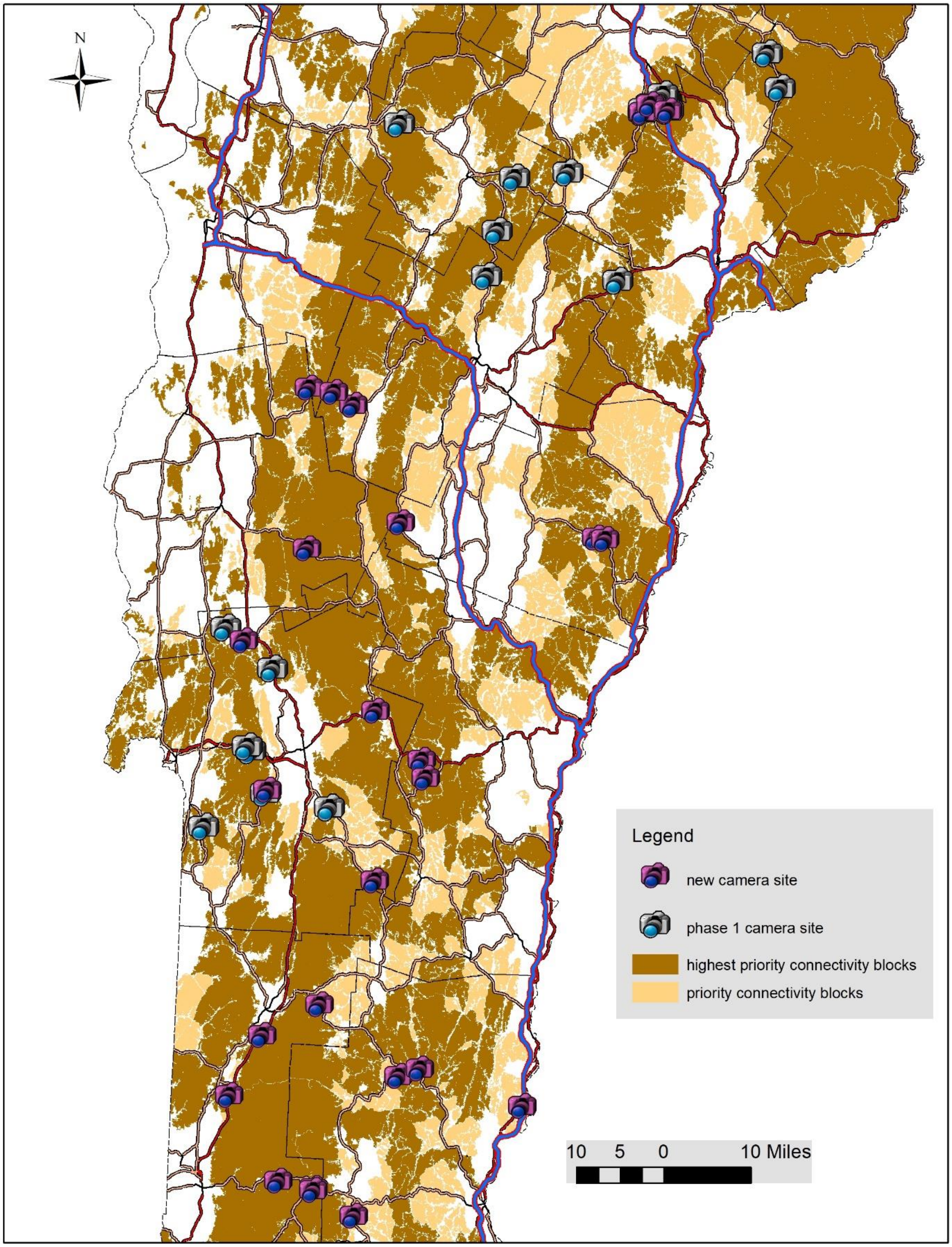

Figure 1. Map of current and previous ("phase 1") site locations and Vermont Conservation Design Biofinder connectivity block layers (VT ANR 2016).

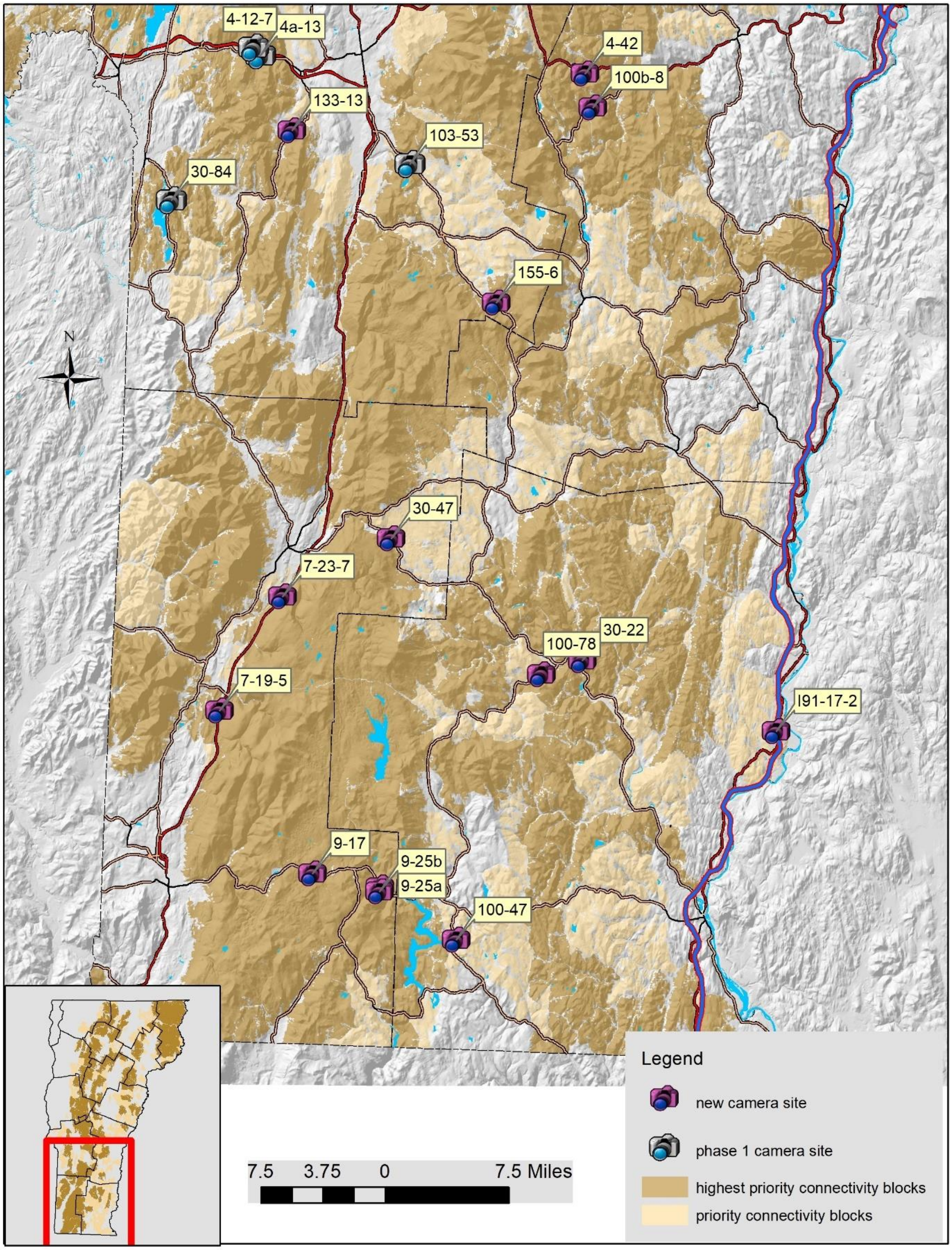

Figure 2. Map of site locations in southern Vermont and Vermont Conservation Design Biofinder connectivity block layers (VT ANR 2016).

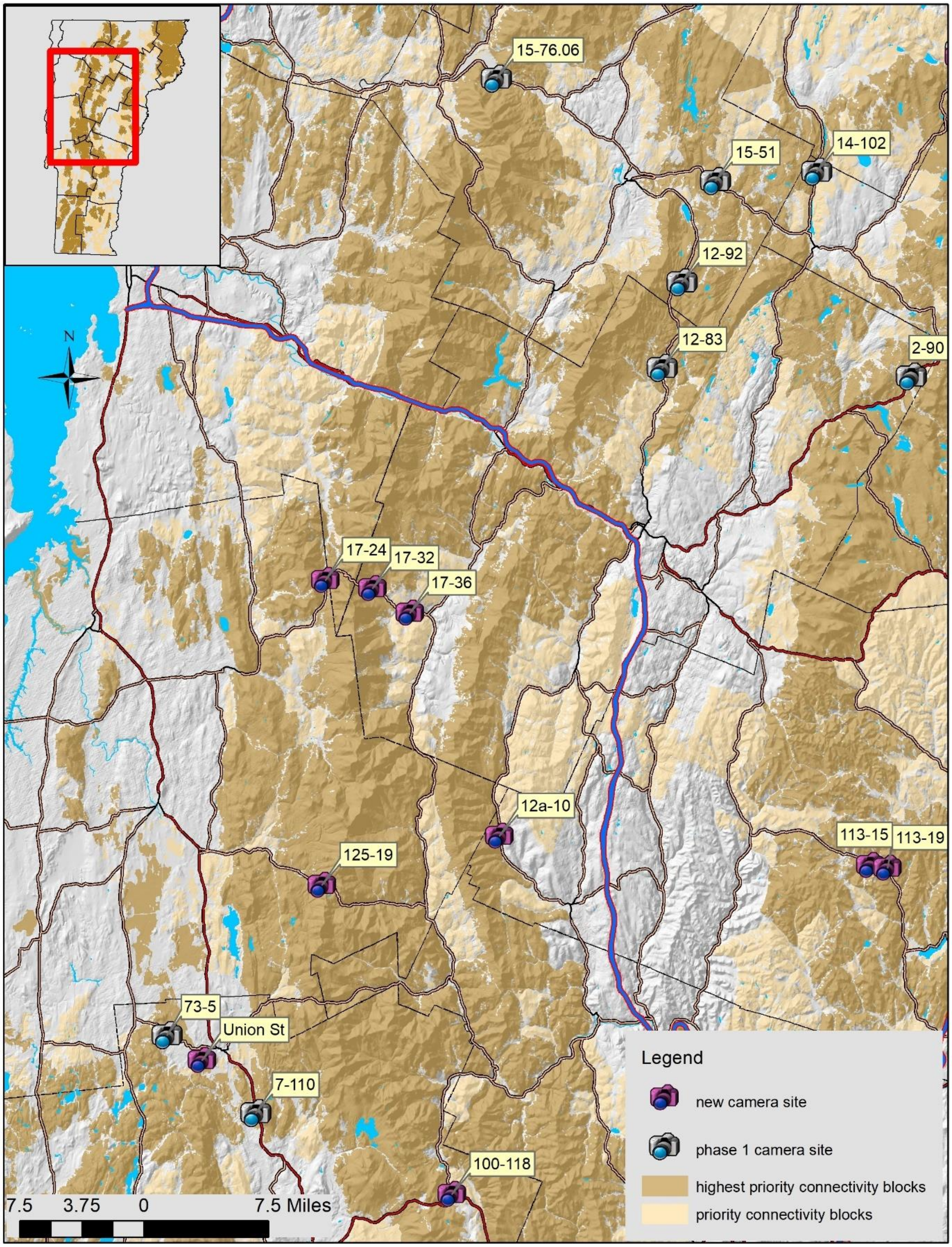

Figure 3. Map of site locations in central Vermont and Vermont Conservation Design Biofinder connectivity block layers (VT ANR 2016).

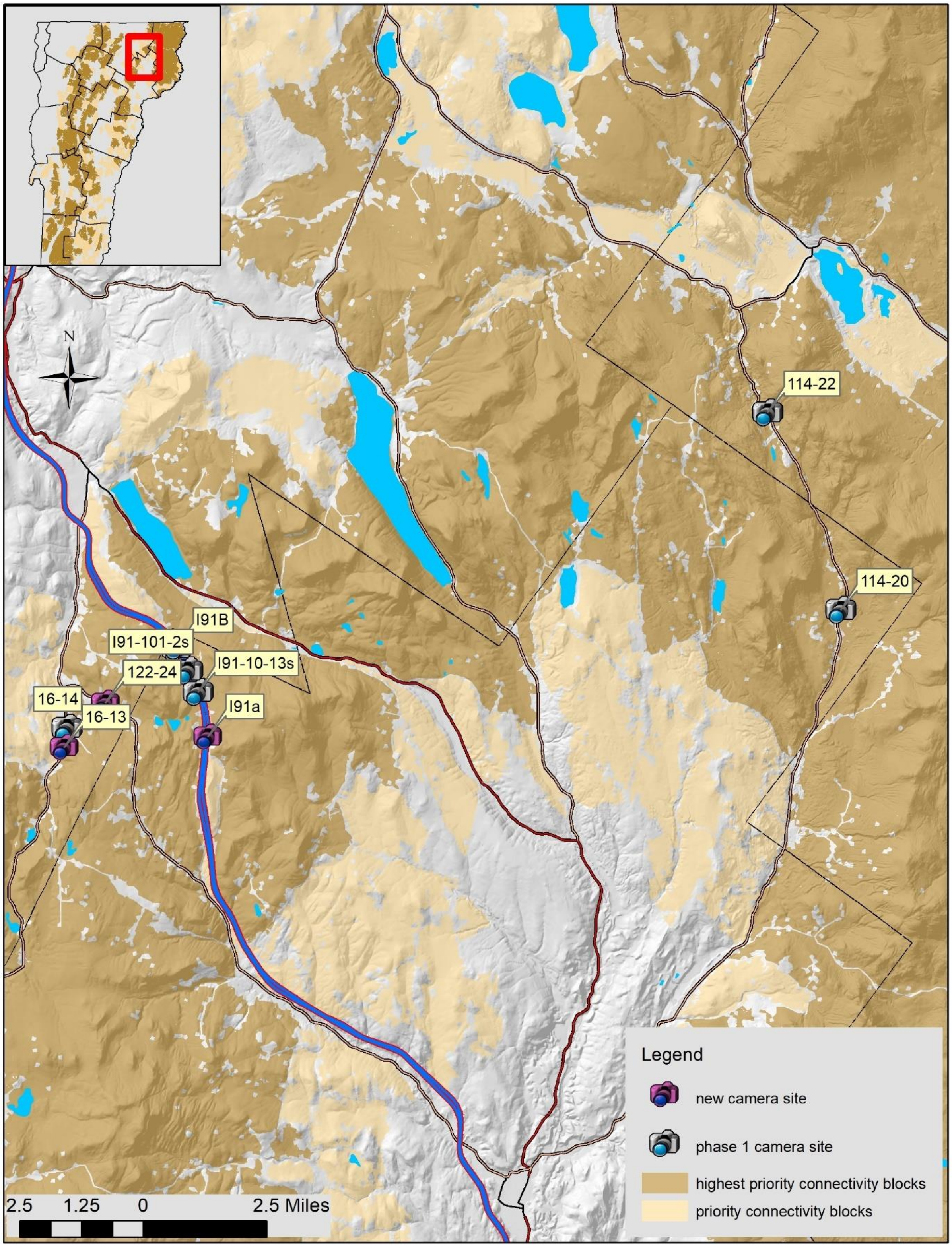

Figure 4. Map of site locations in northeastern Vermont and Vermont Conservation Design Biofinder connectivity block layers (VT ANR 2016).

Table 2. Structure design type categories used to guide study site selection process. More details are found in Appendix B.

structure design type
old box culvert
"V" bottom box culvert
new precast box culvert
arch culvert
pipe culvert
squash pipe culvert
span
span with footing shelf

2.2. Data collection

ReConyx PC900 cameras were used to collect data on wildlife movement through transportation structures. Cameras were mounted on trees, bridge piers, or bridge abutments. 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 larger bridge spans, up to six 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, 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.

Winter wildlife tracking

We visited each of the 26 sites at least twice over the course of the project to collect tracking data on wildlife movement on roadways. Tracking work was performed during periods of adequate snowcover in the winters of 2016-2017, 2017-2018, and 2018-2019. Wildlife tracks were collected on a 1600' transect along the roadway, centered on the monitored culvert or bridge. Tracks were identified to the lowest possible taxonomic level (most often to species, small rodents were disregarded) and recorded with a GPS device. Track-based evidence of successful wildlife road crossing was recorded for all terrestrial species.

2.3. Data Management

We visually scanned all photos for the presence of wildlife, identified to species, and recorded each detection in a database created for this project. One detection was recorded 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 tens of thousands of photos over the 3-month camera check interval. 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 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. Mink (*Neovison vison*), long tailed weasels (*Mustela frenata*) and short tailed weasels (*M. ermine*) were sometimes difficult to differentiate to species in game camera photos and were therefore combined into a "small weasel" category for analysis. 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 3) comprised of larger terrestrial mammals that are mostly wide-ranging and/or are of some conservation interest.

Table 3: List of focal species and number of sites detected.

Species	# of sites detected
Coyote	13
Deer	17
Moose	1
Black Bear	10
Bobcat	12
Fisher	7
Grey Fox	5
Otter	4
Red Fox	11
Skunk	6
Small weasel	15

3. Results

3.1. Wildlife Detections and Through-Passages

Structure-focused game cameras recorded a total of 660,000 photos over 18,057 monitoring days across all sites, yielding 1,641 detections of 13 focal species and 1,347 focal species through-passages (Table 4; examples of game camera photos can be found in Appendix B). Detections of an additional 9 secondary species were recorded (Table 5), while small mammals (mice, voles, chipmunks, squirrels) and other birds (wood duck, bald eagle, great blue heron, crows, ravens, woodcock, mergansers, swallows etc.) were photographed but not recorded. Raccoons were particularly abundant at most sites, having been recorded using 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 5). Deer had by far the highest mean through-passage frequency of all focal species (3.78 per 100 days). Bobcat, fisher, small weasel, and coyote had more moderate through-passage frequencies (between 0.15 and 0.64 per 100 days). Grey fox, red fox, skunk, otter, bear, and skunk all had low mean through-passage frequencies (< 0.15 per 100 days), and only a small number of detections and no through-passages were recorded for moose.

Variation of site through-passage data

There was substantial variation of focal species through-passage frequencies across all sites (Figure 6). Moderate or high through-passage frequencies were recorded for the 13 sites (between 1.0 and 15.0 through-passages per 100 days). Sites 9-25b and 4-42 hosted high through-passage frequencies (36.5 and 49.2 through-passages per 100 days, respectively) compared to other sites, mostly due to a high frequency of use by deer. Eleven of 26 sites had very low through-passage frequencies (>1.0 through-passage per 100 days), with two of these having no through-passage use at all. This was surprising, considering that we systematically selected sites that appeared most suitable for use by focal species for through-passages, based on both "fatal flaws" criteria from Kintsch and Cramer (2011) that indicated unsuitability for wildlife use, and the refined understanding of the influence of site characteristics on wildlife use from Phase 1 results (Marangelo and Farrell 2016), where sites with "fragmented" structural connectivity through a site were rarely used by focal species.

The large number of low-use sites prompted us to 1) investigate additional site characteristics that might explain low wildlife through-passage frequencies; and 2) incorporate data from Phase 1 (Marangelo and Farrell 2016) from a subset of sites (Table 6) that met Phase 2 site selection criteria into the current analysis of the effects of structure design on focal species through-passage. This allowed us to increase our sample size for our analysis on the effects of structure design on wildlife through-passage frequency.

Site characteristics that inhibit wildlife through-passage

Early on, we observed that wildlife through-passage was low or non-existent at sites that hosted new culverts and bridges constructed to replace structures that failed in 2011 during tropical storm Irene. We specifically sought to include these structures for this study because they were built to current specifications that incorporate flood resiliency and AOP compatibility values. However, all these structures lacked vegetation cover around stream entrances and exits, due to the footprint of structure replacement construction work. There were 6 of these structure in this study (Table 1). All six of these sites had very low focal species through-passage frequencies (Figure 6).

Table 4: Number of detections (both through-passages and approaches) of focal species by site.

Site	4-42	7-19-5	7-23-8	9-17	9-25a	9-25b	12a-10	16-13*	17-24	17-32	17-36	30-22	30-47	100-47	100-78	100-118	100a-8	113-15	113-19	122-24*	125-19	133-13*	155-6	I91-17.2	I91a*	Union St	**Total**
Coyote	9	0	3	0	1	21	0	1	0	0	0	0	0	2	0	1	10	2	10	1	0	14	0	0	5	0	**80**
Deer	386	6	6	53	42	217	2	4	2	0	26	0	0	1	0	0	0	4	58	20	0	83	0	35	1	9	**955**
Moose	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Black bear	1	3	5	1	3	4	1	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	3	0	**26**
Bobcat	2	47	6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	3	1	2	44	0	1	21	30	**160**
Fisher	0	13	0	0	0	0	0	17	0	0	1	0	0	0	0	0	0	0	3	62	0	0	2	0	9	0	**107**
Grey fox	0	0	0	0	1	0	0	1	0	0	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	0	**6**
Otter	0	0	0	1	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	12	0	**19**
Red fox	1	0	4	5	7	5	0	13	0	2	31	0	0	0	0	0	0	0	3	1	0	8	0	0	1	0	**81**
Skunk	0	0	0	0	0	0	1	18	0	0	0	0	0	0	0	0	1	0	0	7	0	1	0	0	0	2	**30**
Small weasel[1]	0	0	5	3	0	0	0	100	0	4	0	0	2	6	0	1	1	0	2	7	1	2	4	0	30	8	**176**
Total	**399**	**69**	**29**	**63**	**55**	**247**	**4**	**158**	**5**	**6**	**58**	**0**	**2**	**14**	**1**	**2**	**12**	**8**	**80**	**101**	**3**	**152**	**6**	**36**	**82**	**49**	**1641**
# days[2]	613	601	611	634	586	586	611	1660	492	448	448	357	453	633	453	612	389	609	608	1541	560	1272	428	630	1649	573	**18057**

[1] number of camera monitoring days at a site

*Site carried over from phase 1 of this project – data reflects 4 years of camera monitoring

Table 5: List of secondary terrestrial species detected by cameras.

Secondary species
Raccoon
Woodchuck
Domestic cat
Domestic dog
Lagomorph
Muskrat
Opossum
Porcupine
Turkey

Table 6. Phase 1 camera sites (Marangelo and Farrell 2016) from which data from 2014-2016 was used for analysis of the effects of structure design on wildlife through-passage.

Structure	**Road**	**Town**	**Size class**	**Design type**
114-20	VT 114	Newark	med/lg	*span with footing shelf*
4-12-17	US 4	Ira	small	*pipe*
I91bE	I-91	Sheffield	small	*pipe*
I91bW	I-91	Sheffield	small	*pipe*
I91-101-3s	I-91	Sheffield	small	*pipe*
4A-13	VT 4a	Ira	med/lg	*span*
I91-101-2s	I-91	Sheffield	small	*pipe*
103-53	VT 103	Shrewsbury	med/lg	*V bottom box culvert*
30-84	VT 30	Poultney	med/lg	*span with footing shelf*
73-5	VT 73	Sudbury	med/lg	*span*

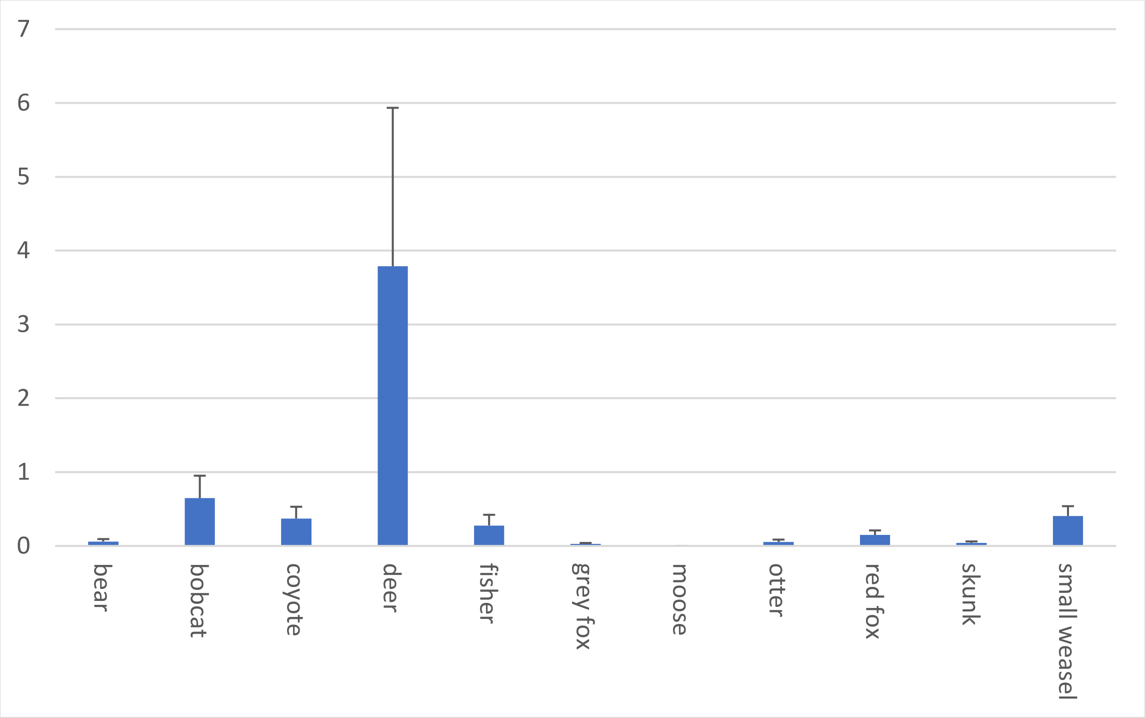

Figure 5. Mean (SE) Passage events per 100 days for each focal species across all sites.

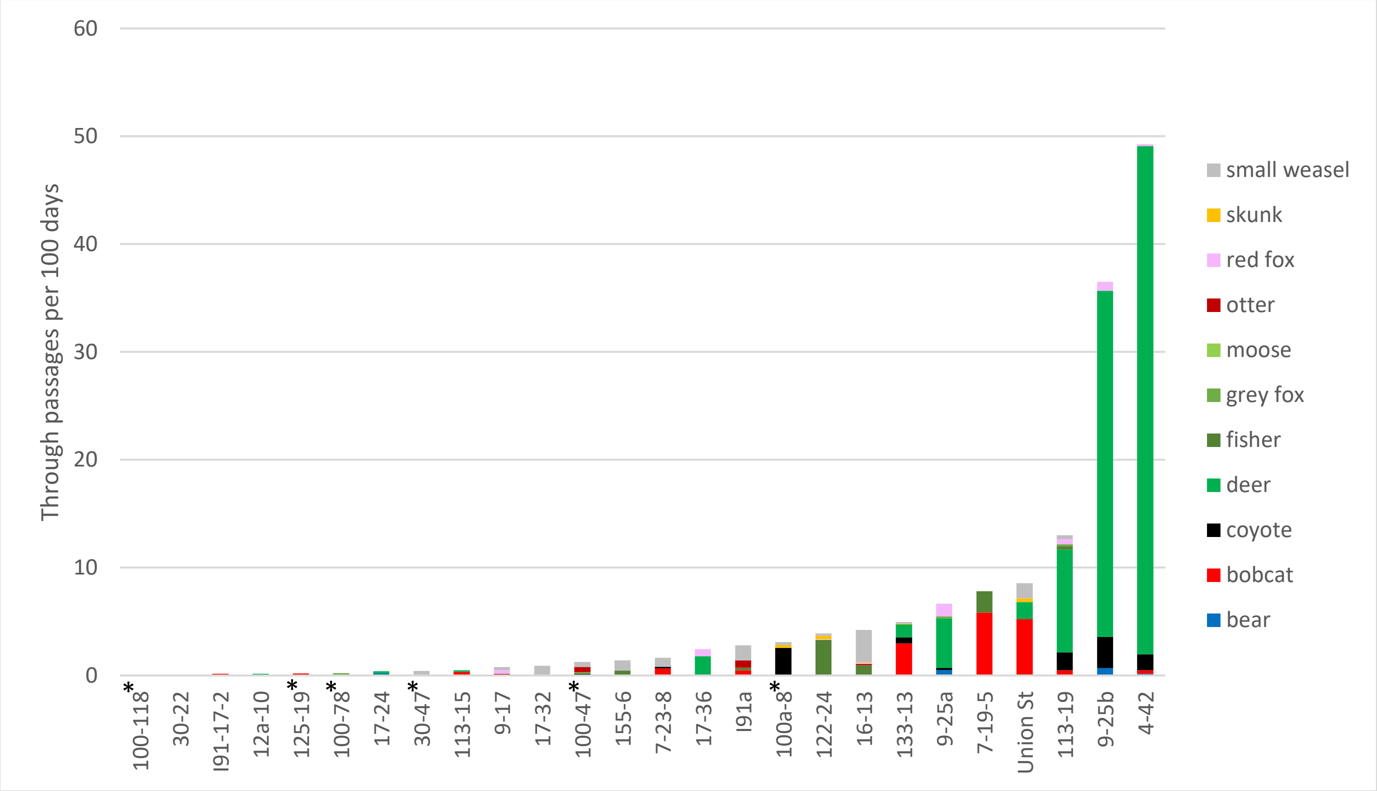

Figure 6. Focal species 100 day through-passage frequency at each site, color coded by species. * new post-Irene structure.

In addition to the post-Irene structures, there were still many additional low-use sites. Upon further examination, these sites appeared to feature more development near transportation structures compared to sites with more wildlife use. While our site selection process screened out potential sites with directly adjacent development, it would have been impossible to achieve the desired number of camera sites for this study if we had used stricter development criteria to screen out all sites that had development in the vicinity. We instead assumed that the levels of development near the camera sites we selected were not enough to substantially impact the frequency of wildlife use of transportation structures.

To assess the influences of nearby development on use of transportation structures by wildlife, we created an index of development influence at each site by 1) identifying likely movement pathways through each site based on contiguous forested habitat within the riparian corridors at each site (Figure 7). Likely movement pathways were hand-digitized from a visual assessment of orthophotos and LIDAR-based hill-shade data layers for pathway identification; 2) creation of a 50m buffer around each dwelling unit (derived from an E911 spatial data layer for VT) within 300m of a culvert or bridge; 3) intersecting these buffers with the movement pathways (Figure 8); 4) calculation of the ratio of the area of intersection of 50m buffer around each residence with the area of the movement pathway. We plotted this index against through-passage frequencies of sites from both Phase 1 and Phase 2 of this project (Figure 9). Because most sites with a development index > 0.1 had through-passage frequencies at or near zero, we selected 0.1 as a threshold to use to identify sites where development likely suppresses through-passage frequencies (Figure 10). This threshold created development index-based site groupings for through-passage frequency data that had significantly different means (p=0.0314; Wilcoxon rank sum test, Figure 11)). We therefore excluded all sites from subsequent analyses on the effects of structure design on through-passage where the development index was > 0.1.

Variation of through-passage data by structure design

To assess the effects of structure design on wildlife through-passage, we first needed to create a classification of structure design types that explicitly links common structure designs with the characteristics and availability of movement surfaces (Table 7). To accomplish this, major design type distinctions needed to be differentiated into sub-groups according to the differences in the characteristics of movement surfaces that they offered (Table 7). This resulted in the creation of some movement surface categories that were exclusive to a particular structure design type (e.g. “round pipebottom” movement surface in *pipe culverts*); movement surface categories that appeared in multiple design types (“dry concrete” occurs in both *V bottom box culverts* and *span with footing shelf* structures); and design categories with multiple movement surfaces (*spans* were comprised of structures with “even bank”, “level floodplain”, or “riprap bank” movement surfaces).

We then compared wildlife through-passage frequencies of structure categorized by both structure design type and movement surfaces. Both Phase 1 and Phase 2 sites were used for this analysis (Table 1 and Table 3), excluding all sites with site characteristics that suppressed wildlife use: new post-Irene structures, sites with fragmented site structural connectivity, or development indices > 0.1 (Figure 12).

Among design types, both *spans* and *span with footing shelf* categories had higher through-passage frequencies compared to other design types (Figure 13). *Old box culverts*, which exclusively consisted of sites with “sheetflow concrete” movement surfaces (Table 7), had comparatively low through passage frequencies. Differences between the mean of the four design categories that consisted of data from more than two sites were significant (ANOVA P=0.004), with paired comparison tests indicating that the differences between the means of *spans* and *old box culvers* and *spans* and *pipe culverts* were significant (Tukey’s p=0.037 and p=0.0043, respectively).

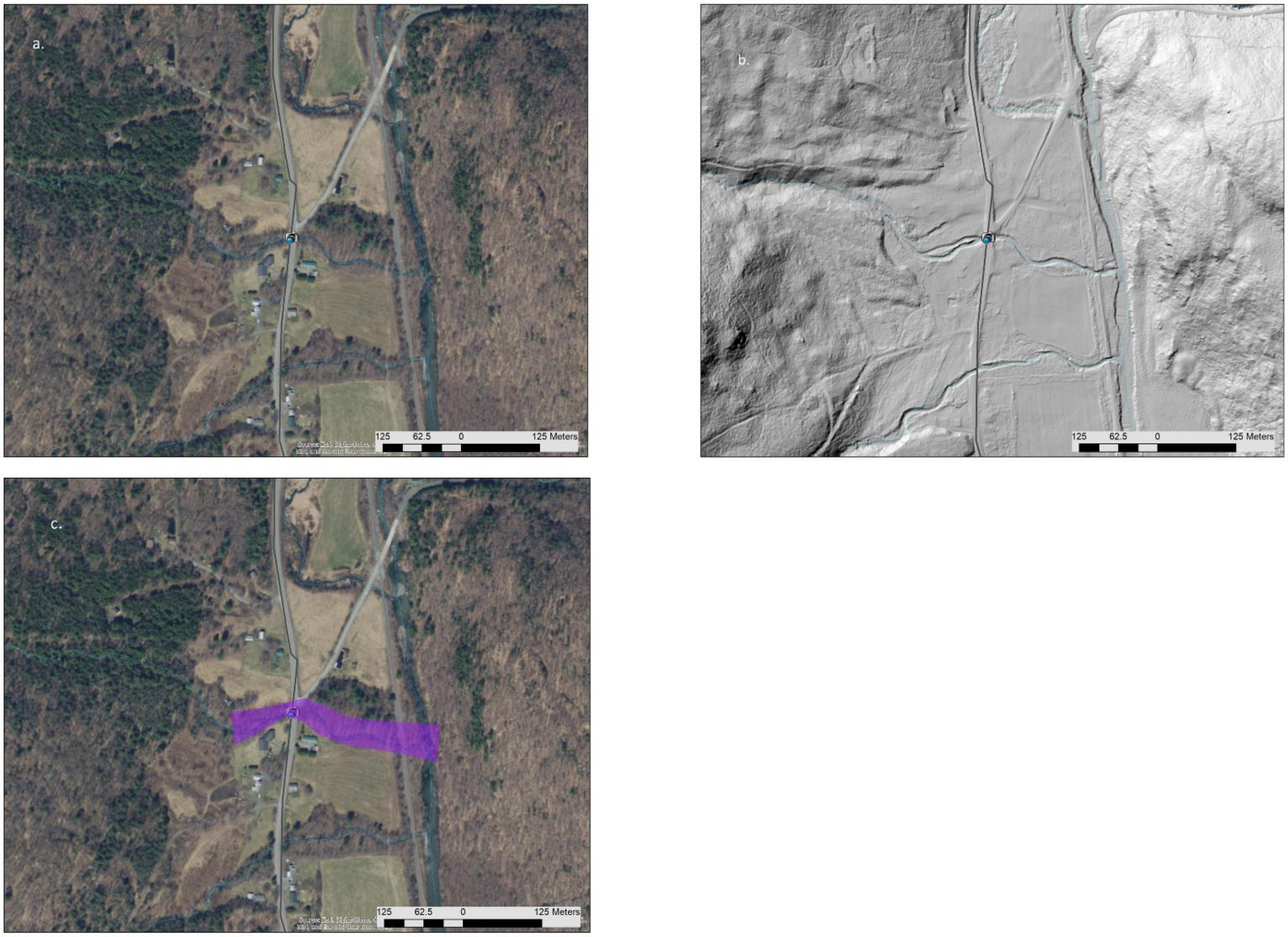

Figure 7. Illustration of the process used to identify likely movement pathways. a) visual identification of forest cover of orthophotos that provides likely movement habitat across a road corridor; b) LIDAR hillshade layer was used to confirm location of riparian corridor; c) polygon of most likely movement pathway was hand digitized from interpretation of a) and b). Site 21a-10, Braintree.

Figure 8. Illustration of 50m buffers around all residences within 300m of a transportation structure (Site 12a-10, Braintree).

Figure 9. Illustration of the intersection of the most likely movement pathway with 50m residence buffers considered "influenced by development". Development index for this site was the proportion of the "influenced by development" within a "most likely movement pathway" to the total pathway area (Site 12a-10, Braintree).

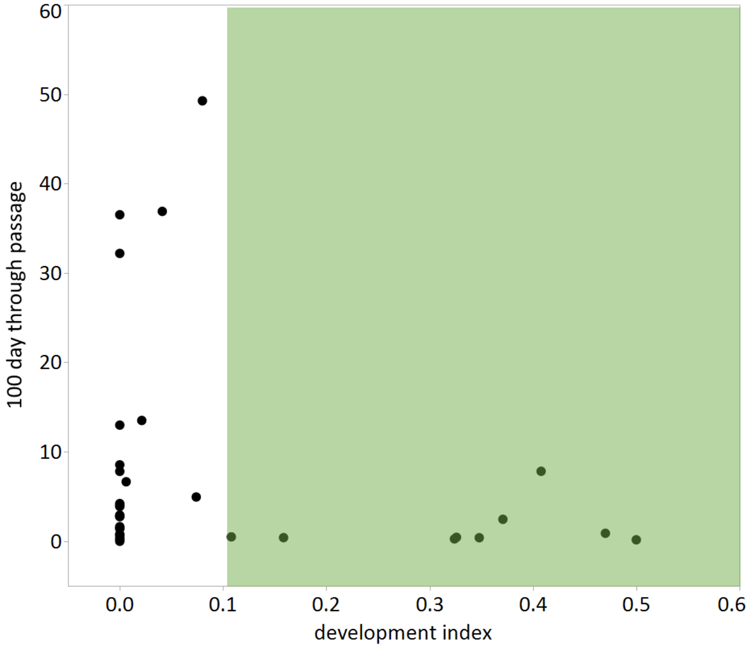

Figure 10. Scatterplot of through-passage frequencies for each site against site development index. Shaded area represents sites that we interpreted had low, development-impaired through-passage frequencies, with a threshold set for all development indices >0.1.

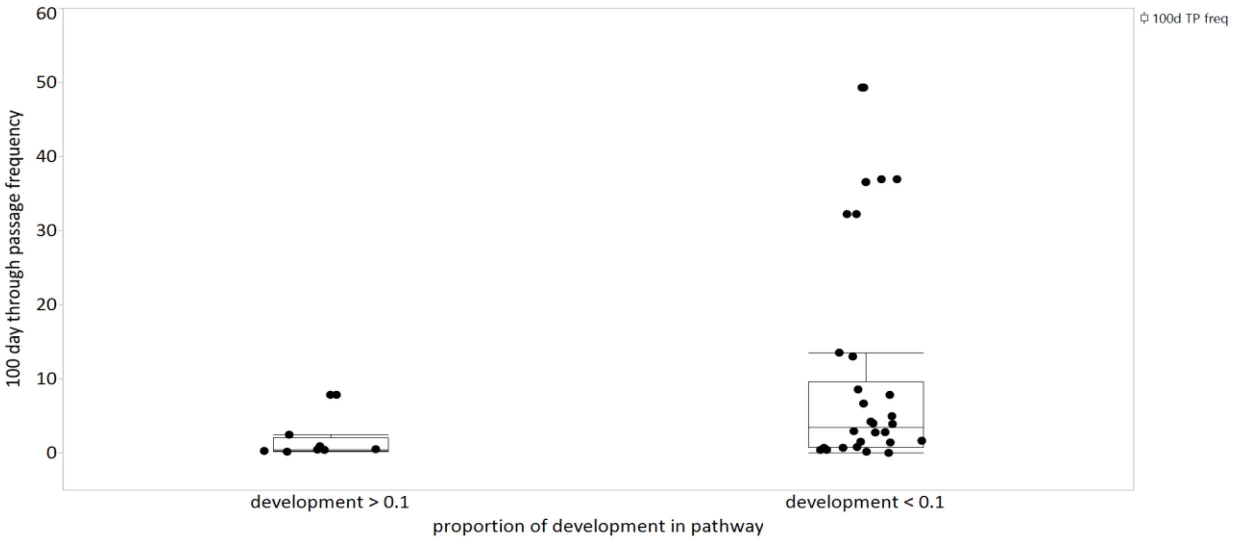

Figure 11. Comparison of 100day through-passage frequencies of sites where the development index <0.1 vs >0.1. Comparison includes sites from project phases 1 and 2, with new Post-Irene structures (6), structures with poor movement surface availability (1), sites with fragmented structural connectivity (4) excluded. Difference between the mean of both groups is statistically significant (Wilcoxon rank-sum test, p=0.031).

Table 7: Structure design categories used for this analysis, predominant movement surfaces found within design categories, and comments on factors governing the relationship between structure design and movement surface availability in structures that otherwise have no PASS "fatal flaws" (Shilling et al 2012). More detail can be found in Appendix B.

structure design type	**movement surface**	**relationships between design and movement surface**	**# of Phase 2 sites**	**# of analysis sites***
arch culvert	dry or partially dry natural streambed	Will have dry movement surface unless structure is undersized	1	1
old box culvert	sheetflow concrete	Flat concrete structure bottoms always wet - only dry if stream is annual.	3	3
"V" bottom box culvert	dry concrete	Dry concrete along edges of culvert bottom	1	2
new precast box culvert	dry gravel/sand/cobble streambank	Low/moderate gradient stream	2	0
	dry boulder/cobble	High gradient stream	2	0
pipe culvert	round pipebottom	Will have dry movement surface unless structure is undersized	4	10
squash pipe	flat pipebottom	Will have dry movement surface unless structure is undersized	2	1
span	riprap bank	Bank stabilization used under a majority of bridge spans	3	1
	even streambank	From fine, fluvial-deposited sediment; low gradient rivers wher bank stabilization not needed	2	2
	dry streambed	Driven by stream hydrology: abnormally flashy streams with periods of no flow	2	2
	level floodplain	Predominantly fine particle substrate; typically found under valley-spanning bridges	2	3
span with concrete footing shelf	dry concrete	Footings built on shallow ledge offer flat dry movment surfaces at most river flows	2	2

* All sites from Phase 1 and Phase 2 of this study, excluding sites that had 1) Fragmented structural connectivity; 2) Poor movement surface availability; 3) development index >0.1.

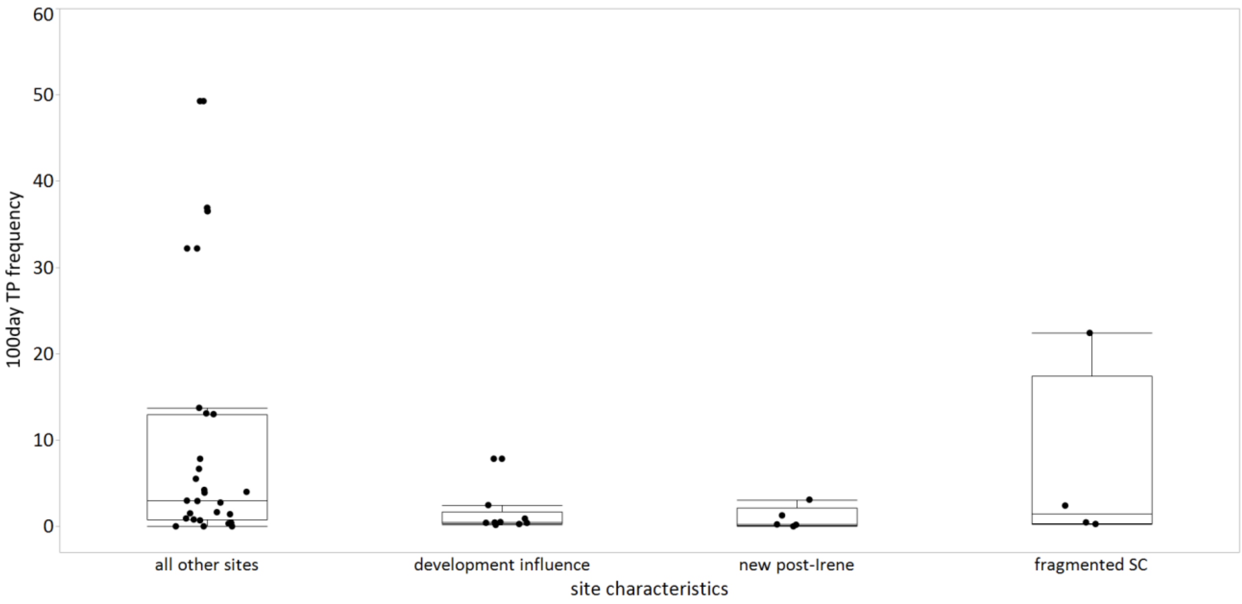

Figure 12. Through-passage frequency data for all Phase 2 and Phase 1 (Marangelo and Farrell 2016) sites by site characteristic category, with overlaid box-plots. Category specific results were used to justify excluding sites in the “development influence”, “new post-Irene” and “fragmented SC (Structural Connectivity)” categories from the analysis on the effects of structure design on through-passage frequency.

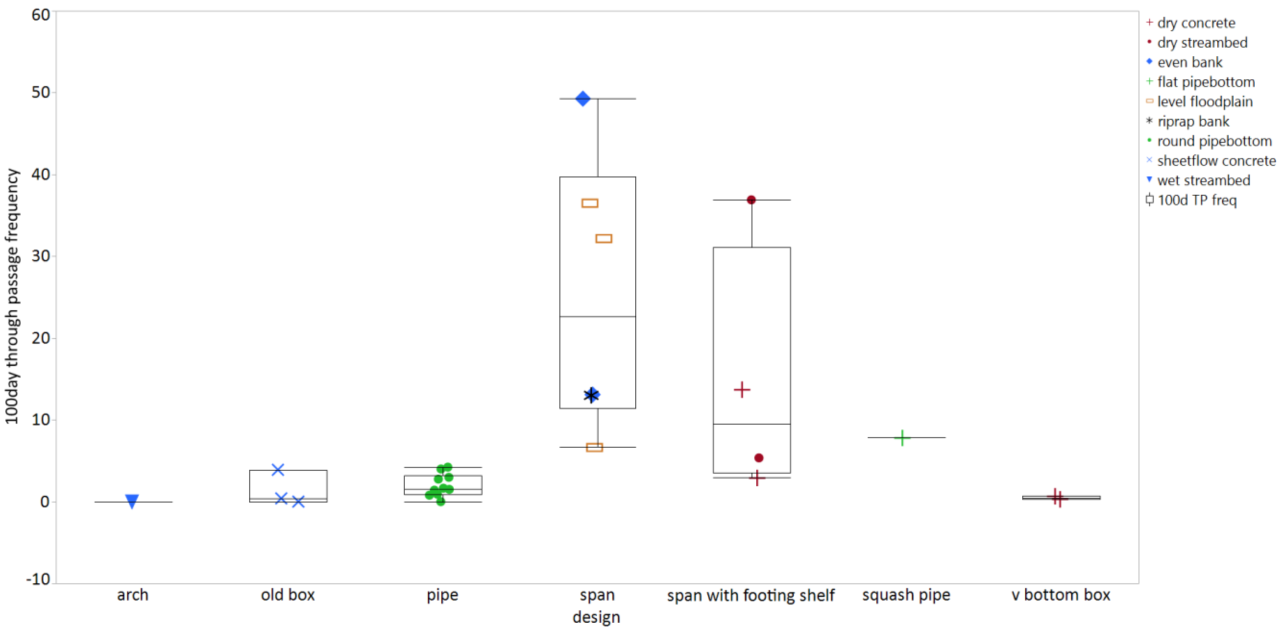

Figure 13. Through-passage frequency data points and box plots categorized by structure design type. Data point markers correspond to specific movement surfaces. ANOVA means test (excluding categories with <3 data points)

indicated significant differences between the means (p=0.004), with differences between spans and old box culverts and spans and pipe culverts significant (Tukey's p=0.037 and p=0.0043, respectively).

Because *spans* are large size-class structures large enough to allow deer movement along with other focal species, and deer represented a large proportion of overall through-passages in the dataset, we excluded deer from the data and re-ran the analysis. *Spans* and *spans with footing shelves* continued to perform well in terms of through-passage frequencies when deer were excluded compared to other design types, but differences were not as large, and differences between the 4 design categories with more than 2 sites were not quite statistically significant (ANOVA p=0.0504 (Figure 14)).

Through-passage data for *pipe culverts* were remarkably consistent compared to other structure types.

While we had only one site with a *squash pipe* design (Site 7-19-5; an additional *squash pipe* site (Site 113-15) was excluded from the analysis due to near-by development), this site had a remarkably high through-passage frequency – the largest of any culvert in either phase of this study. The scarcity of this design type prevented us from incorporating larger numbers of this design type into this study.

Effects of Movement Surfaces

When through-passages between movement surface types were compared, movement surface categories that contained primarily data from *spans* tended to have higher through-passage frequencies, especially when deer were included in the data (Figures 15 and 16). In particular, "dry streambed", "even floodplain", and "even streambank" movement surface categories featured higher through-passage frequencies, both including and excluding deer through-passage data. Statistical comparisons between mean through-passage frequency data were not attempted because of the predominantly low sample sizes within each movement surface category.

Results from some movement surface categories reflected direct relationships with structure design types, as movement surfaces were integral parts of the structures. For example, "sheetflow concrete" movement surfaces were found only in *old box culverts* with flat concrete bottoms, and "round pipebottom" were found only in *pipe culverts*, and "flat pipebottom" was only found in *squash pipes*.

Through-passage frequencies were enhanced at a small number of sites by the existence of viable secondary movement surfaces (Figure 17). Most often, secondary movement surfaces were wet stream bottoms with substrate of gravel, cobble, and sand, and were used by deer. For example, Site 113-19 in Vershire hosted, in addition to the movement of other focal species over the rip-rap streambanks (bobcat, fisher, coyote, small weasel), deer moving over the inundated stream-bottom under the bridge span. Through-passage frequency at this site is likely higher than what otherwise would have been recorded over the main "riprap" movement surface, which deer typically avoid.

Size-based Structure Design Factors

The relationship between stream bankfull width and structure width intuitively would seem to influence over the amount of dry movement surface availability in a structure: the wider a structure is with respect to the size of the stream, the greater the availability consistently dry movement surfaces for wildlife. To investigate this relationship, we calculated stream bankfull width from hydraulic geometry equations for Vermont (using estimates of upstream watershed area using USGS streamstats (https://streamstats.usgs.gov/ss/)) and plotted bankfull width estimates against through-passage frequencies, excluding all sites in low wildlife use categories from Figure 12.

There was a significant linear relationship between through-passage frequency and the ratio of structure width to stream bankfull width (Figure 18; $y = -2.802852 + 11.409249 * x$; p=.0.0015). However, the strength of this relationship is heavily influenced by the effect of bridge *spans*, which had much higher through-passage frequencies than other structure design types, and whose larger through-passage frequencies were attributable to their ability to be used by deer. When spans were excluded from the through-passage frequency data, there was no apparent relationship between through-passage frequency and structure width/bankfull width ratio (Figure 19). Nor was there a significant relationship when deer data were excluded (Figure 20).

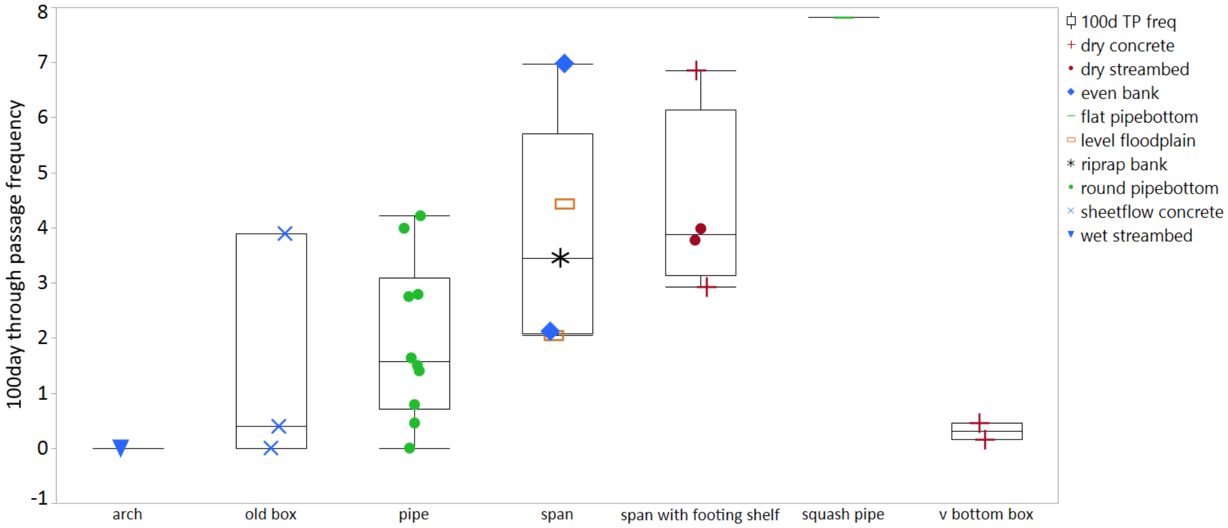

Figure 14. Through-passage frequency data with deer excluded and box plots categorized by structure design type. Data point markers correspond to specific movement surfaces. ANOVA means test (excluding categories with <3 data points) indicated that differences in category means were nearly significant (p=0.0504).

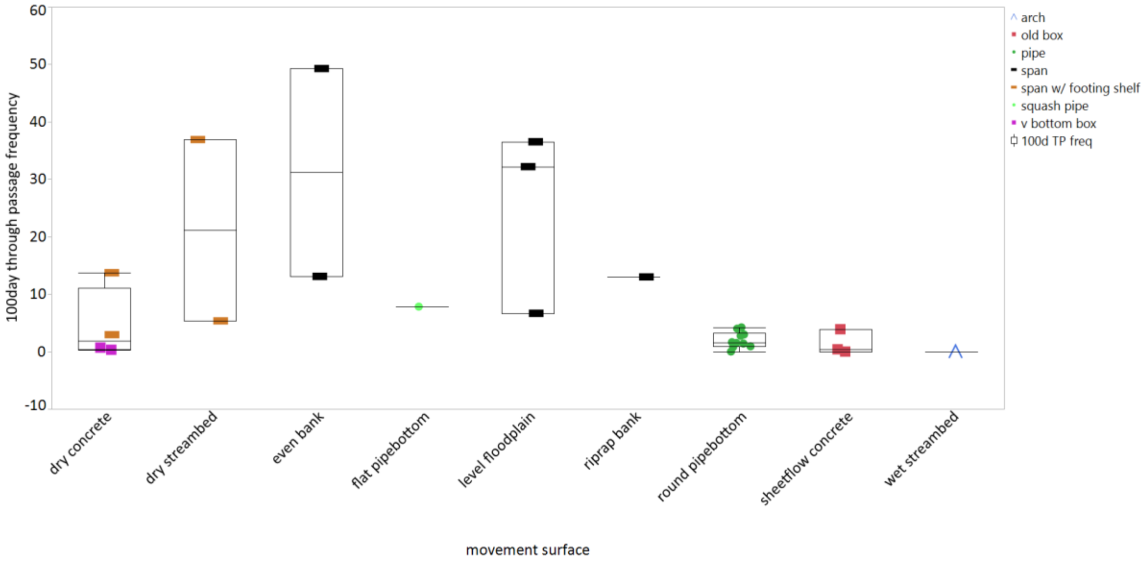

Figure 15. Through-passage frequency data categorized by movement surface type, with data point markers corresponding to specific structure design types. Movement surfaces that corresponded with bridge spans generally had greater through-passage frequencies.

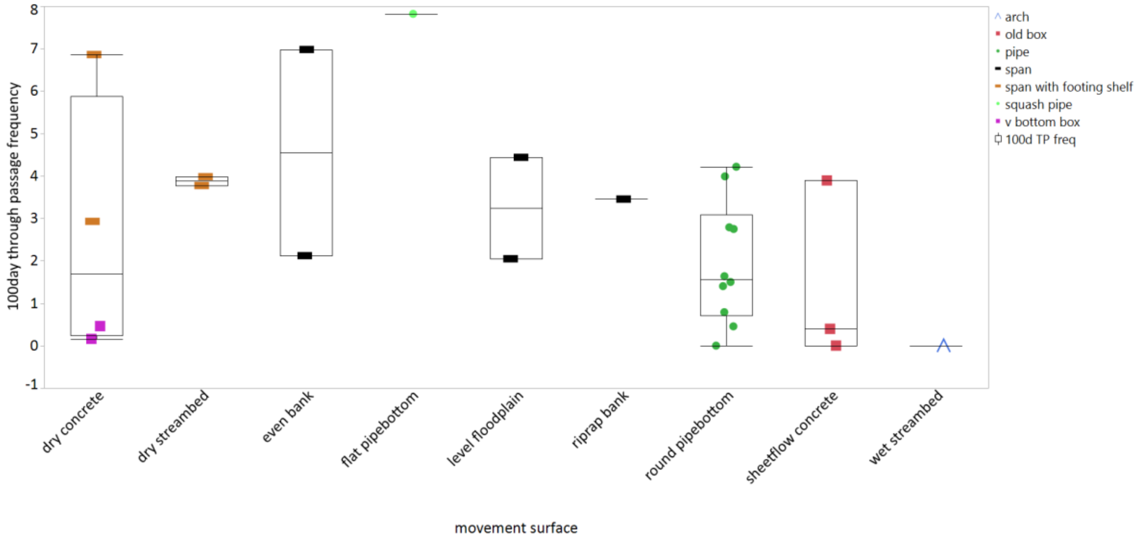

Figure 16. Through-passage frequency data with deer excluded, categorized by movement surface type, with data point markers corresponding to specific structure design types. Movement surfaces that corresponded with bridge spans generally had greater through-passage frequencies.

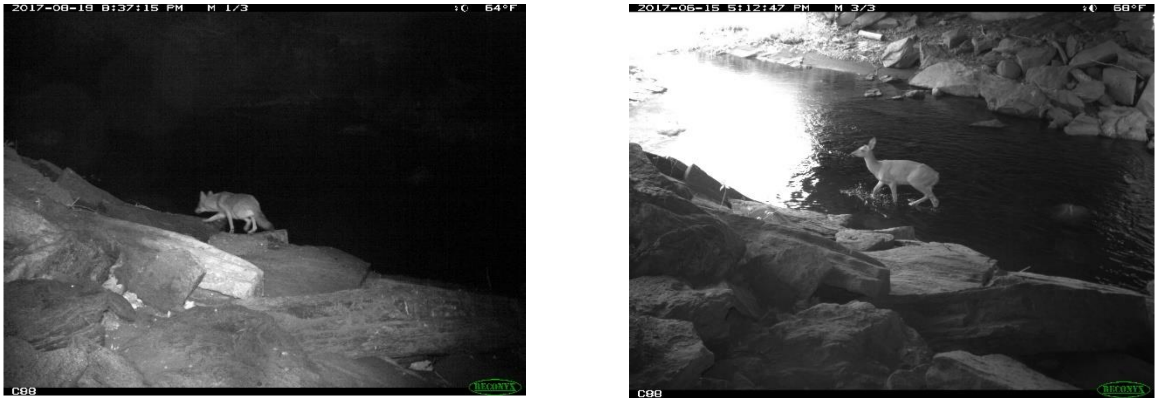

Figure 17. Illustration of secondary movement surface at site 113-19, Vershire. Most species used the riprap bank, while deer used a “wet streambed” secondary movement surface composed mostly of sand/gravel.

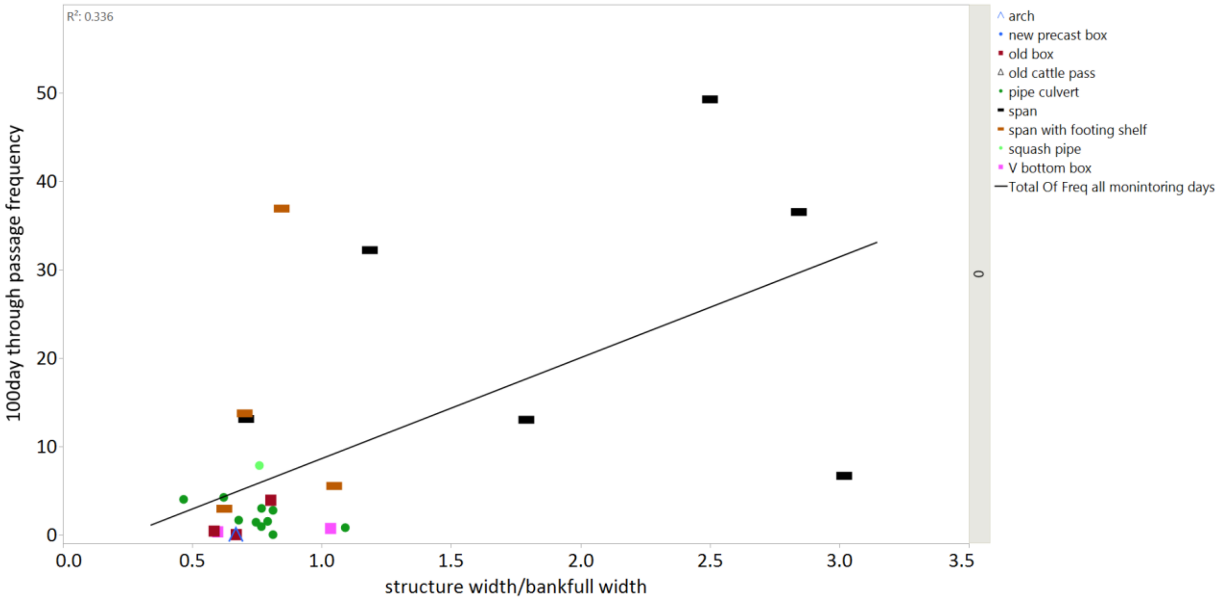

Figure 18. Scatter plot of through-passage frequencies vs. structure width/bankfull width ratio. The linear relationship between the two variables was significant (y=-2.802852 + 11.409249*x; p=.0.0015).

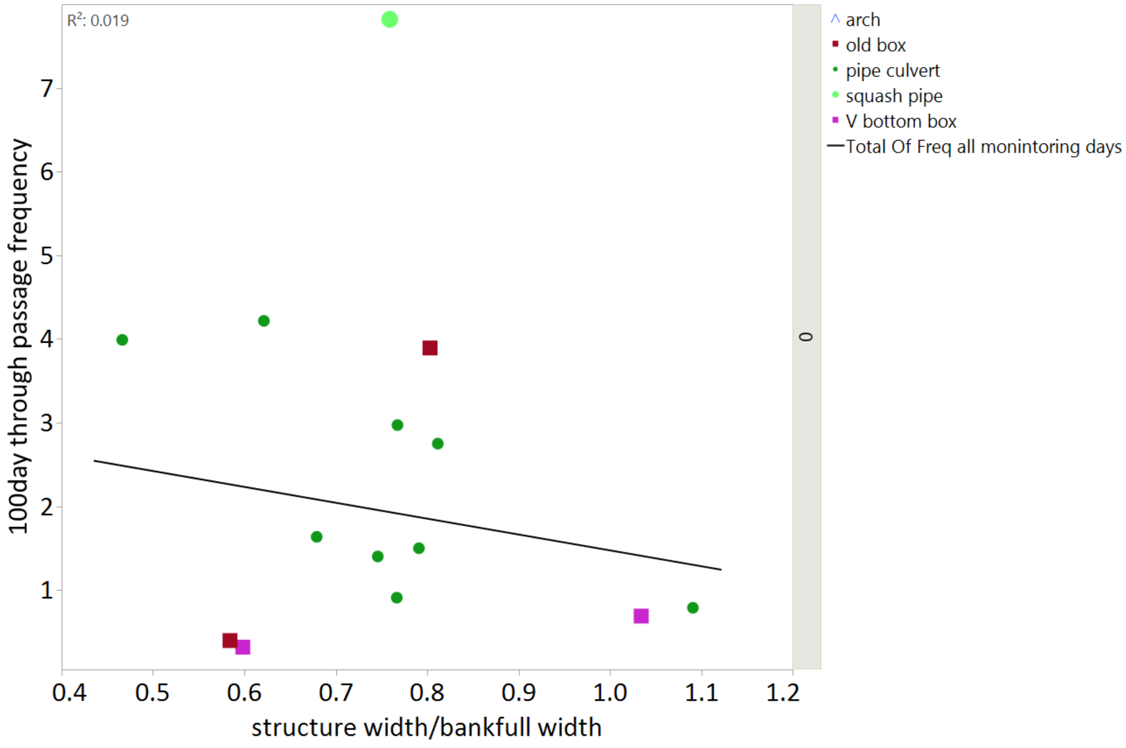

Figure 19. Scatter plot of through-passage frequencies vs. structure width/bankfull width ratio, excluding data from all spans.

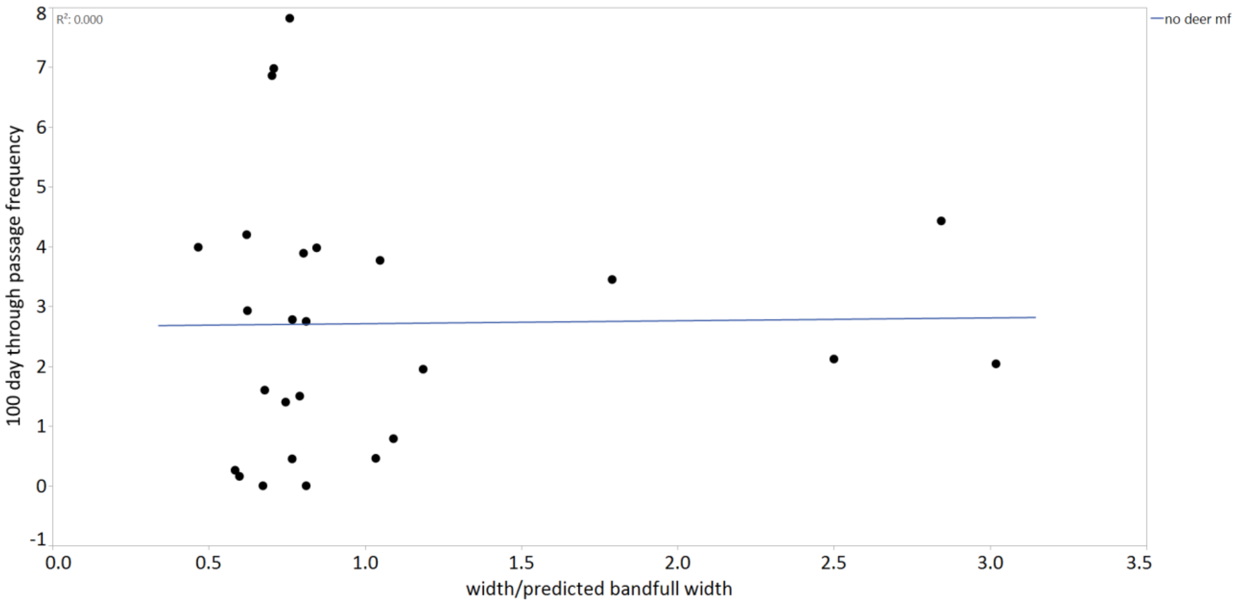

Figure 20. Scatter plot of through-passage frequencies vs. structure width/bankfull width ratio, excluding all deer through-passages.

3.2. Winter Tracking

Winter tracking efforts recorded 311 successful wildlife road crossings across all study sites between the winter of 2016-17 and 2018-19 over 86 site tracking visits (Table 7, detailed maps of tracking observations are in Appendix C).

Coyote road crossings out-numbered all other species, accounting for over 44% of all detected road crossings (Table 8), and crossed the road much more frequently compared to through-passages (Figure 21). Conversely, only one moose crossing was detected during an informal site visit that was not part of the organized tracking effort. Tracking data was particularly helpful in interpreting through-passage data by documenting wildlife activity around sites for which few through-passages were recorded. For example, Site 12a-10 in Braintree had surprisingly few wildlife through-passages (with a development index > 0.1), 1, yet had 2 deer and 6 coyote road crossings in the vicinity of the structure (Figure 22).

3.3. Movement Guild-based Analytical Framework

A primary objective of Phase 1 of this project (Marangelo and Farrell 2016) was to test the Movement Guild analytical framework for identifying the most likely species use patterns of a given transportation structure based on size characteristics. For this analysis, we integrated Phase 1 and Phase 2 through-passage data. Results (Figure 23) were predominantly consistent with the movement guild groupings recommended by Marangelo and Farrell (2016).

Table 8. Number of winter road crossing tracking detections at each site. Due to the difficulty of identifying every track to species, some observations are classified by the lowest possible species grouping (e.g. “fox” or “small weasel”. Coyotes were most strongly represented in this dataset, accounting for over 44% of all detected road crossings.

site	Bobcat	Deer	Moose	Ermine	Fisher	Mink	Small weasel	Coyote	Fox	Gray Fox	Red Fox	Otter	Skunk	Total
100-118	1				6	1		6						14
100-47						1					1	1		3
100-78					1						4			5
100-8a					1	2		2						5
113-15						1		4						5
113-19		1			2						2			5
122-24		1			4			9	2		2			18
125-19		1			2	3		5						11
12a-10		2		1				6	2		2		1	14
133-13	1					1		4					2	8
155-6	1					1		8		2				12
16-13					1	2		8						11
17-24					1	1		7	2					11
17-32	2				6	3		5			1			17
17-36						3		22			3			28
30-22		6						2						8
30-47						1					2			3
4-42			1		1	1		4						7
7-19-5		14			2		1	7			1			25
7-23-7	2	1			1			3			1			8
9-17	1				1	1		1			1		1	6
9-25a&b		2				2		2			8			14
I91-17-2		5			4			3						12
I91a	1			1	2	2	2	8						16
Union St	9				1	6		18	4		1			39
Total	18	33		2	36	33	3	138	10	2	31	1	4	311

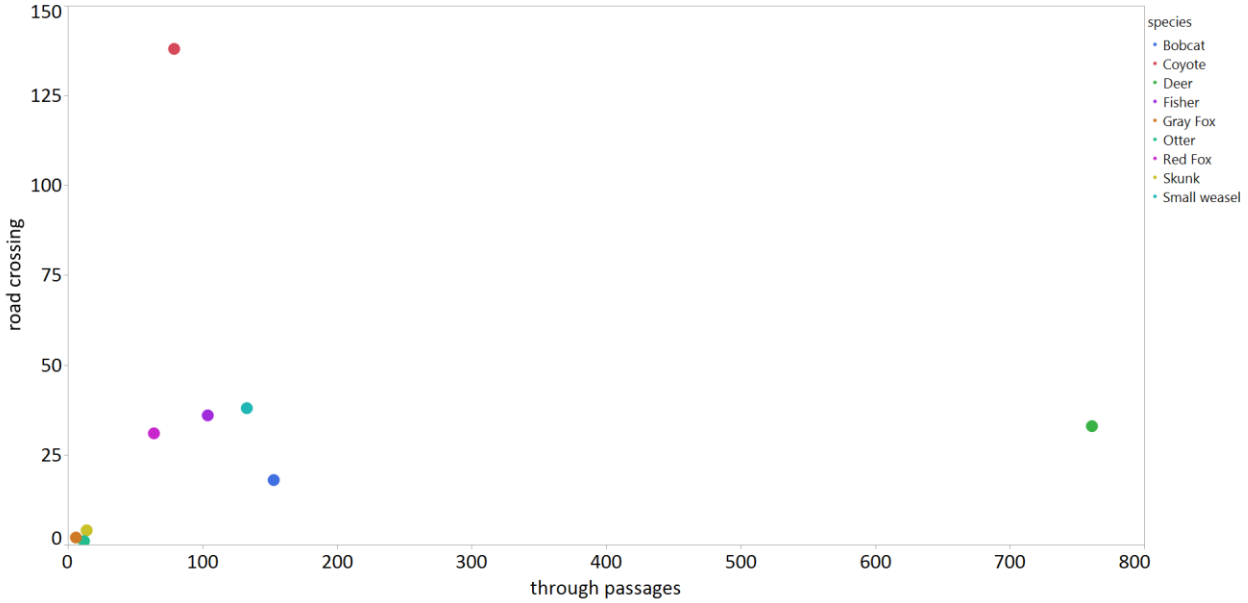

Figure 21. Scatterplot of number of detected road crossings vs number of through-passages for each species. Coyotes crossed the road much more frequently than they used structures for through-passage, while deer had much lower number of road crossings with respect to the number of detected through-passages, possibly due to less movement of deer in winter.

Figure 22. Map of focal species road crossings at Site 12-10, (Braintree). This site had only 1 deer through-passage during the project and had a relatively high development index. Road crossings denoted by red circles. Red circles without a species identifier represent crossings of non-focal species.

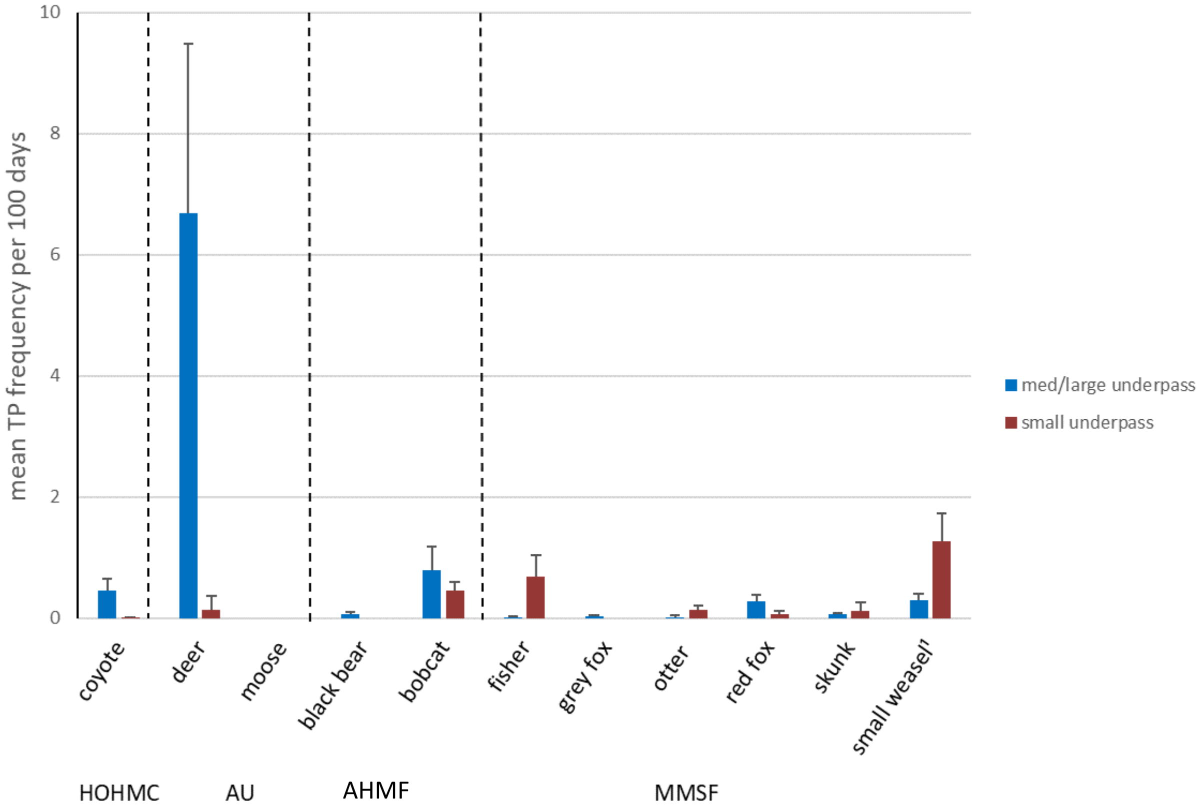

Figure 23. Mean species through-passage detections per site with Phase 1 data added (Marangelo and Farrell 2016) to the current dataset. Movement guild species groupings appear below Y axis. HOHMC and AU guilds are expected to be limited to using medium or large size class structures.

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), and further refined by the results of Phase 1 of this project (Marangelo and Farrell 2016). Phase 2 study results were consistent with this framework with one exception. We observed six bear through-passages at four sites in our results, whereas in Phase 1, no bear through-passages were recorded. All bear through-passages were recorded at large size-class structures. Moreover, we have photo documentation of a bear bypassing a small culvert in the process of crossing the road, with a both a first detection and return detection (Figure 24). In this case, the bear chose to walk over the road rather than pass through the culvert. With this limited set of observations, we recommend provisionally removing bears from the set of species that can be expected to use small size class structures. Bears are considered part of the AHMF movement guild, which are expected to be able to use structures in all size classes. Our data on bear through-passage provides no reason to expect that bears would be unable to use medium size-class underpasses, so we recommend a more flexible classification framework of guilds and species where bears are removed from the set of AHMF species expected to be able to use small size class structures, yet are retained in the set of AHMF species that can be expected to use medium and large size class structures. The revised movement guild groupings appear in Table 9.

Figure 24. Bear bypassing a culvert while apparently moving towards crossing US 7 in Sunderland, with photo from return trip (Site 7-19-5, *squash pipe*). This culvert was regularly used by bobcat for through-passage.

Table 9: Revised size class/movement guild species composition framework for potential focal species use of transportation structures across a range of structure types and sizes based on results of the present study, with bear being removed from the set of AHMF species considered likely to use small size class structures. Derived by Marangelo and Farrell (2016) which in turn was a modified version of the initial groupings 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)	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)	lynx, bobcat, bear
		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)	lynx, bobcat, bear
		Adaptive Ungulates (AU)	deer, moose
		High Openness High Mobility Carnivores (HOHMC)	cougar, wolf, coyote

4. Discussion

4.1. The effects of structure design on Focal Species Use of Bridges and Culverts in Vermont

Site characteristics

We anticipated that this research would improve our understanding of the complexity of the interacting factors that influence transportation structure usability by wildlife, systematically building on insights gained from Marangelo and Farrell (2016). And while our results indeed achieved this objective, similar to Marangelo and Farrell (2016), we again needed to alter our analysis to incorporate new unanticipated factors influencing through-passage data. We incorporated the state of our understanding of the effects of site characteristic gained from Marangelo and Farrell (2016) into our site selection criteria for the present study, only to discover that there were additional unaccounted for site characteristics (the influence of near-site development and vegetative cover around structure ends) that were still influencing results from the current project phase. Neither the current phase of this project nor its predecessor (Marangelo and Farrell 2016) had as an explicit objective to better understand the effects of site characteristics (such as structural connectivity of forested habitat or nearby development) on wildlife use of transportation structures. Marangelo and Farrell (2016) started from the assumption that the existing Passage Assessment System as modified for Vermont by Shilling et al (2012) provided enough information to select culverts and bridges for the project that would be most likely to be used by wildlife. The need to adjust our analysis to account for unanticipated influences on through-passage data reflects the complexity of the interacting site of site and structure characteristics that influence the frequency of wildlife through-passage.

Our methods to develop an index of site development influence was a cursory attempt to quantify a factor that appeared to be influencing wildlife through-passage frequencies. Our distance threshold of 50m from a residence was a best-judgement determination, as researching the effects of development on species movement patterns of multiple species and then integrating this research into a single distance number was beyond the scope of this study. The resulting index of site development, while leaving much room for refinement, nevertheless proved useful in providing important insights on a site characteristic factor that influences wildlife use of transportation structures.

Vegetative cover around structure ends proved to be another important site characteristic because it was completely lacking from several sites that we explicitly targeted for this project: new culverts and bridges built to replace structures that failed during tropical storm Irene in 2011. An additional site with low-through-passage frequency (pipe culvert 9-17) also lacked vegetative cover around the downstream culvert end, perhaps as well explaining its low through-passage frequency.

Indeed, the complexity of the relationships between site characteristics, structure characteristics, and through -passage frequency is perhaps best illustrated by our ability, as with Site 9-17, to further interpret through-passage data by considering how a combination of site-specific features at individual sites influenced through-passage frequency. For example, our general characterization of *old box culverts* is that they are poor for wildlife use, based on the premise that the perpetually wet "sheetflow concrete" movement surface discourages species that prefer to avoid walking in water. However, there is one culvert in this category (Site 122-24 in Glover, VT) which has higher through-passage frequencies than others. This culvert hosts a much smaller stream, and portions of the culvert bottom are dry or nearly dry in the summer months, allowing more frequent stream use.

Structure design

To facilitate our analysis, we have striven to create the fewest number of classification categories for structure design for the sake of developing a classification scheme useful for transportation infrastructure management. Enlarging the number of categories (or further subdividing existing categories) to accommodate most of the factors that we can identify by drilling down into individual datapoints would create an unwieldly classification framework that would likely be less useful for transportation infrastructure management. Moreover, we struggled to obtain meaningful sample sizes within many of the existing structure design categories, a problem that would only be compounded by a more complex classification framework.

Indeed, the result of a large number of Phase 2 sites with little focal-species use further adds to our conviction that "ideal" sites for wildlife passage are very rare, and nearly all potential sites around transportation structures have at least some issues which can potentially suppress if not discourage wildlife use. Nevertheless, we can distill some useful generalizations on wildlife structure use for each of our structure design categories:

Spans

These designs appear best suited for maximizing wildlife through-passage. Their large size is amenable to the broadest set of wildlife species for through-passage (Figure 25), and they sometimes host more than one movement surface type. Standard practices such as rip-rapping streambanks[2] hinder wildlife usability however, unless the hydrological conditions under a bridge allow for the deposition of finder sediments that fill up lower elevation riprap crevices, or entirely preclude the need for extensive bank armoring under the span. Some *spans* serve valley-spanning roadway alignment needs. Such *spans* are the largest of all, have very large structure width/bankfull width ratios (all >2.5 in this study), do not constrict floodplains with abutments, and thus can offer the width of an entire floodplain for under-road wildlife movement. Moreover, it is possible that our through-passage frequency data under-represents wildlife use of the larger bridges in particular, as cameras need to detect animals over longer movement detection fields than at smaller structures, making them less sensitive to detecting smaller species.

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[2] Current VTrans design specifications for new spans include depositing grubbing material over riprap above high water to provide a better wildlife movement surface.

Figure 25. Examples of the variety of movement surface types that *spans* can provide. Upper left: "even floodplain" under valley-spanning bridge (9-25b, Searsburg). Upper right: "dry streambed" in a *span with footing shelf* where nearly all through-passages occurred on the streambed, which was typically entirely dry during summer months. Lower left: "riprap" streambank movement surface commonly found under many *spans* (not a project site). Lower right: "even streambank" of fine sediments under a *span* that does not cross an entire river valley (Union Street, Brandon, VT).

Spans with footing shelves

Spans constructed on shallow ledge often feature exposed concrete footings, which create level dry "shelves" that wildlife use for movement. Older structures that are dramatically undersized for their stream can still support wildlife movement via footing shelves (Sites 4a-13 and 114-20 from Marangelo and Farrell (2016); Figure 26), even when the structure otherwise offers no other movement surface due to perpetual inundation. These structure types are relatively scarce, but illustrate how the offering of a dry, level, movement surface can create opportunity for wildlife through-passage in a structure that would otherwise be unusable. Footing shelves as narrow as 6" were used by species such as bobcat (Figure 26). Results from these structures suggest that shelves constructed specifically to provide a usable movement surface in any type of structure can offer benefits of increased through-passage, given suitable site characteristics.

Two of the four spans with footing shelves (Sites 133-13 and 30-84) conveyed intermittent streams. At these sites, "Dry streambeds" were the movement surfaces used by wildlife in these structures instead of "dry concrete".

Figure 26. Bobcat through passages *at span with footing shelves* structure design types (Site 114-20 (left) and 4a-13 (right)).

Old box culverts

These structures typically receive use by only species that tolerate wet movement surfaces. Their bottoms are flat and unless they host an intermittent stream, feature a movement surface characterized by the sheetflow of water over flat concrete under nearly all flow conditions "sheetflow concrete" (Figure 27). These structures are especially abundant throughout Vermont.

Figure 27. Examples of old box culverts with "sheetflow concrete" movement surface. Site 30-22 (West Townshend) and 15-76 (Cambridge, Marangelo and Farrelll 2016).

New pre-cast box culverts

We were not able to adequately assess wildlife use of these structures, because all hosted large construction footprints that were cleared of all vegetation 5-7 years ago and are just starting to recover. The cleared construction sites offered little cover for wildlife, and thus these sites were seldom used by focal species. However, these structures are likely to offer superior wildlife through-passage opportunity once woody vegetative cover regenerates on old construction footprints, as long as stream processes allow for the development of dry substrate fine enough to be tolerated by hooved species such as deer. Structures that need to accommodate high gradient streams are appear to be an exception, offering inferior dry movement surfaces of very coarse substrate (boulders and large cobble, as exemplified by Site 30-47 (Figure 28), that are not suitable for deer or moose (AU movement guild). In situations where it is desirable to maximize wildlife movement opportunity, specific wildlife-movement design features should be considered at high-gradient sites, such as specific movement shelves separate from the culvert bottom or especially large structure width/bankfull width ratios that can accommodate some development of floodplain-like features within the structure, approaching those more commonly found on bridge spans (>1.5, Figure 17).

Figure 28. Examples of different movement surface development in *new precast box culverts*. Upper right and left: High water velocity during high streamflow events precludes the retainment of fine particles within the structure, resulting in a movement surface predominantly composed of boulder-sized particles. Site 30-47, Winhall. Lower left: movement surface of finer particle substrate. Site 100-47, Wilmington.

V-bottomed box culverts

These structures are very rare – we found only 2 suitable for game cameras. By channeling water into the center of the culvert, they offer superior dry movement surface availability compared to the wet flat bottoms of typical of *old box culverts* (Figure 29). Project data probably does not reflect the potential of this design type for encouraging wildlife through-passage, as both structures studied were much longer than most wildlife prefer (both were over 235 feet long). Since newly constructed box culverts are likely to feature embedded designs, and are thus more likely to have more favorable movement surfaces than dry concrete (Figure 11), the relevance of "V bottomed box culverts" to the management of road corridors for increased permeability for wildlife appears questionable.

Figure 29. Example of a *V bottom box culvert*, with "dry concrete" movement surfaces along culvert walls. Site I91-17-2, Putney.

Pipe culverts

Corrugated metal pipe culverts were consistently used by smaller wildlife species, with relatively low through-passage frequencies. They constitute the most numerous type of structure in this study, and were used by most species in Movement Guilds (Table 8) that are expected to be able to pass through small size class structure. While not ideal for wildlife passage, given favorable site characteristics and a not overly small width/bankfull width ratio, they provide a limited degree of functionality for wildlife through-passage.

Squash pipes

These structures are rarely encountered – we identified only 2 that were suitable for cameras in this study. One of these had a high development index, and the other (Site 7-19-5; Figure 23) hosted the highest through passage frequency of any culvert monitored during both phases of this study. This latter site suggests that *squash pipes* may be a superior design compared to pipe culverts for wildlife through-passage. *Squash pipes* have a greater degree of dry movement surface availability compared to equivalently sized round pipes, and the movement surfaces that wildlife would use for through-passage are generally less curved.

Arch culverts

These bottomless culvert designs were rarely encountered during our site scouting efforts, and we identified only 2 for game-camera monitoring sites, one of which proved unsuitable for wildlife movement because of the degree of inundation. We therefore have little data to substantiate their suitability for providing wildlife through-passage. However, provided that these structures are large enough with respect to their host streams to provide dry movement surfaces and the gradient is not so steep so that a structure can retain a streambed of gravel, sand, and smaller cobbles, these structures will likely excel at providing through-passage opportunity for wildlife.

Other structure characteristics

While it is likely that structures with wider structure width/bankfull width ratios are generally better for through-passage, we cannot definitively conclude this based on our project data. As previously noted, the significant positive relationship in Figure 17 is accounted for by deer through-passage, which predominantly used spans in this study. Spans tended to have larger width/stream bankfull width ratios than culverts simply because longer bridges are often needed to fulfill roadbed alignment needs, which sometimes requires spans over river valleys. It is possible that the lack of a positive relationship when bridge spans (and deer) are excluded (Figures 15 and 16) may be influenced by two low-through-passage culverts with ratios >0.8, one of which was much longer than ideal for wildlife use, and the other of which had little vegetative cover on one end. In general, however it appears that many *pipe culverts* with lower width/stream bankfull width ratios (between 0.5 and 1.0) are hydrologically variable enough to permit at least some wildlife movement opportunity under typical low-flow conditions.

Comments on the influence of stream gradient

Stream gradient interacted with design type in ways that appeared to influence the usability of transportation structures by wildlife. Our PASS-based (Shilling et al 2012) site screening criteria eliminated low-gradient road stream crossings from camera monitoring, simply because these crossings tend to have structure-inundating deep, slow moving, or still water that precludes wildlife use. Conversely, higher gradient stream road crossing settings may influence structure design in a way that reduces usability by wildlife. Newer AOP-compatible box culvert designs are typically embedded and feature natural substrates designed to have characteristics similar to natural stream channels. In higher gradient settings, these culverts often only retain boulder-sized particles (Figure 25), which render a structure usable for a smaller variety of species, excluding deer and moose. We monitored four new pre-cast box culverts with an embedded substrate AOP compatible design. While through-passage data at these sites were likely suppressed by the lack of vegetative cover from the footprint of recent culvert replacement work, our understanding of wildlife movement surface suitability suggests that high gradient structures would at the very least preclude deer use because of the rough, coarse-particle substrate. If wildlife passage optimization is desired at a proposed structure replacement site with a high gradient road stream crossing, the structure – whether it be a precast box culvert or a span - may need to be designed specifically to provide the kind of even movement surfaces that would maximize the wildlife crossing value of the structure.

Insights from tracking data

Because each visit to a site to collect road tracking data occurs under different tracking conditions, and these conditions can change rapidly due to shifts in weather, temperature, and precipitation, the use of this data for between-site comparisons is problematic. This data is instead best interpreted as offering a snapshot of incidence of over-road movement of wildlife during a limited number of days during the winter, and species road crossing data is perhaps best limited to comparisons with structure though-passage data. Project tracking results illustrated that wildlife road crossing activity was notable as sites with low through-passage frequencies, both at sites that were development influenced (17-32 and 12a-10) and sites that had less suitable movement surfaces (Site 30-22, an *old box culvert* with “sheetflow concrete” movement surface; See tracking maps in Appendix C).

It is notable that coyote road crossings were particularly common – they represented 44% of all the documented road crossings (Table 7), while coyotes account for only 4.9% of all camera detections, and only 5.8% of all through-passages. Coyotes are clearly more comfortable crossing over roadways compared to under roadways. This is consistent with results from Marangelo (2017), which documented from habitat focused game cameras that coyotes were detected more frequently away from roads than near culverts compared to other species.

Not all species-specific tracking data can be interpreted similarly however. For example, there are very few deer road crossings compared to the number of deer through-passages (Figure 20). It is likely that this difference is a result of behavioral differences of deer in the winter vs. other months, with movement generally being greater in seasons that lack snow cover.

Inferences on the status of the suitability of transportation structures for wildlife through-passage

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. As noted earlier, roughly 10% of structures on highways that we considered for this study 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 (9 sites). It is therefore reasonable to conclude that roughly 4.3% of the transportation structures within highway segments that intersect with connectivity spatial data layers in Vermont structures are currently well-suited for focal species through-passages in terms of site and structural characteristics.

Human site visitation and other potential influencing factors on focal species through-passage

While we have clarified the effects of structure design, structure size, and site characteristics in this study, additional clarification could be gained by better understanding the effects of frequent human site visitation on wildlife use. In particular, Site 9-25a in Searsbug VT is a large valley-spanning bridge, under which is a large, level floodplain that appears ideal for wildlife movement. However, this site had the lowest through-passage frequency of all spans that hosted similar “level floodplain” movement surfaces (lowest data point in the “level floodplain” category on Figure 11), despite the structure being specifically designed with wildlife movement in mind. A nearby parking area off old Rt 9 encourages a high frequency of human visitation at this site, which appears to deter wildlife use. Indeed, most of the documented wildlife movement at this site occurred on the opposite side of the river, which featured only a sloping movement surface composed of boulders and riprap, and little human visitation. This location is where a lynx was detected in 2015 by VTF&W, using the same game camera.

Similarly, it is possible that invasive species may form vegetation thickets around transportation structure that are difficult for wildlife to move through. Several sites visited during study site scouting efforts for this study were potentially impacted in this way by Japanese knotweed and at least in one case, black swallowwort.

4.2. Modified Movement Guild – Transportation Structure Size Class Framework

Marangelo and Farrell (2016) concluded that a modified movement guild framework appeared to be useful for making predictive generalizations about species use of structures with specific size characteristics. These generalizations can inform efforts to make targeted conservation investments to make structures more suitable for through-passage use by replacing or retrofitting structures to wildlife-friendly specifications.

Our recommendation of provisionally deleting bears from the list of AMFH species that are likely to use small structures contrasts with the original PASS framework developed in the western US (Kintsch and Cramer 2011), where small size class structures are considered usable by bears, and by at least one observation in Maine of a bear using a culvert to move under a roadway. The framework in Table 8, while presently useful for managing road corridor/transportation interactions, should be left open to additional modification/revision if warranted by future observations.

Indeed, we are only able to attest to the usefulness of the movement guild-structure size class relationships in terms of the species that we 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.

A lack of our ability to characterize moose movement preferences is the most important deficiency of our dataset. With the statewide moose population down to approximately 2,000 animals (VT Fish and Wildlife estimate), collecting data on their preferences for structure use is difficult. The observation of fresh moose tracks around structure 4-42 in Bridgewater (a large size structure with even substrate suitable for moose), where the moose chose to cross over the road surface rather than under the bridge, is the only datapoint on moose road crossing for this species in 4 years of effort.

4.3. Recommendations

Several recommendations can be derived from project results for increasing the usability of culverts and bridges by wildlife for under-road movement in Vermont:

- At sites where wildlife crossing is an important value, re-plant construction footprints of any site where mature vegetation was cleared for the construction of the replacement structure and/or temporary structure. Currently, site construction footprints are planted with grass (and sometimes a small number of widely spaced trees) and then either left alone or, in some cases, mowed. Plantings should ideally, after 5-10 years of maturation, create enough cover to help facilitate wildlife movement, yet should not form thickets that might impede movement through a structure. As there is still debate over best practices for ecological restoration plantings, persons with specific expertise should be consulted with to develop construction site planting guidelines to promote the development of vegetative cover for wildlife.
    - Also, whenever possible, prohibit mowing of the construction footprint area. There are 2 sites from the current phase of the project where has been observed within the open construction footprints: Site 100-78 in Jamacia, and Site 100-118 in Killington (where the land that is being mowed is part of Gifford Woods State Park!). Mowing will preclude the development of vegetative cover that will make structure use by wildlife more likely.
- Where cost-efficient road stream crossings are needed and there are lesser-priority wildlife movement values along a particular road corridor segment, consider using *squash pipes* instead of round *pipe culverts*.
- Embedded stream crossings in *new precast box culverts* that host high-gradient streams probably needs to be specifically designed to offer a separate wildlife movement surface, as the structure will otherwise only offer coarse boulder substrate that is suitable to fewer wildlife species for through-passage. This is especially true if the structure is going to be large enough to allow the use of ungulates (deer in particular).

- Closely assess at the potential impacts of nearby development when deciding whether or not to make conservation-related investments in transportation structures for improving wildlife passage. The development index offered by this project can be either used for this purpose or refined through further study.

5. Conclusions

Results from this study illustrate some important relationships between transportation structure design characteristics and wildlife use of road-stream crossings for under-road movement. Specifically, results illustrate how relationships between structure design characteristics and wildlife through-passage are more straightforward in non-embedded culverts (*old box culverts*, *V bottom box culverts*, *pipe culverts*, and *squash pipes*) because movement surface availability and substrate type for wildlife is a simple function of structure design-type and structure size with respect to its stream. Conversely, the influence of structure design and other structure characteristics on wildlife through-passage are more complex in embedded culverts, bottomless *arch culverts*, and *spans*, where a given structure is by design intended to retain some "natural" stream channel characteristics. At such sites, wildlife movement surfaces for through-passage can be influenced by interacting factors that determine movement surface particle size characteristics, such as stream hydrology, fluvial erosion/deposition processes, channel morphology, stream gradient at road stream crossings, and stream geomorphic reach function. These factors can act in conjunction with structure size to determine the type and availability of movement surfaces that able to be used by wildlife for through-passage.

Despite this complexity, bridge spans were the most frequently used by the largest variety of wildlife species at the greatest through-passage frequencies. It is also likely that modern embedded concrete box culvert designs will eventually prove valuable for wildlife passage, particularly where stream gradients do not preclude the retainment of finer sand, gravel, and cobble within a structure. But as noted earlier, we were unable to properly assess these structure designs, as all such structures are relatively new and currently feature sites where vegetation cover for wildlife was cleared by structure replacement construction.

Though not a specific objective of this project, by necessity, we also refined our understanding of the influence of site characteristics on wildlife through-passage. We developed a method to quantitatively assess the influence of nearby development on wildlife through-passage and applied this understanding to our analysis of the effects of structure design on wildlife through-passage by excluding data from sites that were ranked high in terms of our site development index. This study adds to the suite of site characteristics that should be considered when evaluating the usability of a transportation structure for wildlife through-passage: structural connectivity natural vegetation (Marangelo and Farrell 2016); and the influence of nearby development on the most likely wildlife movement pathway through a site. The development index developed for this study was rudimentary, so consideration should be given to refining it if explicitly used for evaluating a given site for wildlife through-passage suitability.

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 from 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.

Although not a primary objective of this project, our results enabled us to estimate that only 4.3% of the transportation structures on state highways that occur spatial data layers that define a connected network of forested habitats in Vermont are currently usable by wildlife.

6. References

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Appendix A: Table of site and structural characteristics data used for this analysis.

site	design type	movement surface	development index	new post-Irene structure	project phase	traffic volume (AADT)	structure length	structure height	strucutre width	structure size class	structure width/bankfull width	road elevation above movement surface	structural connectivity
4-42	span	even bank	0.23		2	4097	31.2	30	168	medium/large	2.50	35	diffuse
12-83	span	partially dry streambed	0.35		1	1091	31	12	29	medium/large	1.24	9.5	pinched
2-90	old cattle pass	sheet flow concrete	0.14		1	3300	62	6.25	6	medium/large	1.21	15	fragmented
12-92	old box	sheetflow concrete	0.00		1	1091	30	5.5	11	small	0.58	6	diffuse
7-19-5	squash pipe	flat pipebottom	0.00		2	3800	176	4	8	small	0.76	8	diffuse
4-12-7	pipe culvert	round pipebottom	0.00		1	13398	311	6	6	small	0.77	12	pinched
7-23-8	pipe culvert	round pipebottom	0.00		2	2300	156	3.5	3.5	small	0.68	15	diffuse
9-17	pipe culvert	round pipebottom	0.00		2	4490	127	6	6	small	1.09	10	diffuse
100-118	new precast box	coarse streambank	0.00	YES	2	3100	47	10	24	medium/large	1.09	15	diffuse
100-47	new precast box	cobble/boulder bottom	0.00		2	2900	82	8	18	medium/large	1.33	15	diffuse
100-78	span	riprap bank	0.15	YES	2	1200	31	15	237	medium/large	3.82	20	diffuse
100a-8	span	riprap bank	0.00	YES	2	770	25	7	61	medium/large	1.70	10	pinched
103-53	V bottom box	dry concrete	0.00		1	5903	280	10	15	medium/large	1.03	60	diffuse
113-15	squash pipe	flat pipebottom	0.36		2	267	90	8	11	small	0.93	10	pinched
113-19	span	riprap bank	0.00		2	267	37	16.6	70	medium/large	1.79	20	diffuse
114-20	span with footing shelf	dry concrete	0.00		1	1010	22	5	19.5	small	0.62	7	diffuse
114-22	old box	sheet flow concrete	0.32		1	1010	62	6	7	small	0.53	16	diffuse
122-24	old box	sheet flow concrete	0.00		1 and 2	640	39	4	4	small	0.80	9.5	pinched
125-19	new precast box	cobble/boulder bottom	0.00	YES	2	1000	72	6	20	small	1.78	12	diffuse
12a-10	span	coarse streambank	0.50		2	1033	33	7	22	medium/large	1.11	10	pinched
133-13	span with footing shelf	dry streambed	0.07		1 and 2	1469	29.5	7.8	22	medium/large	1.05	10	pinched
14-102	arch	wet streambed	0.00		1	1300	46	3	5	small	0.67	1	diffuse
15-51	span	riprap bank	0.03		1	5125	26.4	35	128	medium/large	1.94	17	fragmented
155-6	pipe culvert	round pipebottom	0.00		2	600	79	6	6	small	0.75	21	diffuse
15-76	old box	sheetflow concrete	0.01		1	6348	60	5	4	small	0.40	18	fragmented
16-13	pipe culvert	round pipebottom	0.00		1 and 2	1675	100	6	6	small	0.62	22	pinched
16-14	old box	dry streambed	0.41		1	1675	62	4	6.5	small	0.86	14.5	pinched
17-24	arch	dry streambed	0.16		2	791	22	10	74	medium/large	3.05	16	diffuse
17-32	span	even streambank	0.47		2	1314	34	9	42	medium/large	4.51	12	diffuse
17-36	span	riprap bank	0.37		2	2754	29	14	81	medium/large	1.86	18	pinched
30-22	old box	sheetflow concrete	0.00		2	1072	132	6	10	small	0.67	40	pinched
30-47	new precast box	cobble/boulder bottom	0.33	YES	2	2766	93	6	20	small	1.66	25	pinched
30-84	span with footing shelf	dry streambed	0.04		1	1615	33.5	8	23.5	medium/large	0.85	10	pinched
4a-13	span with footing shelf	dry concrete	0.02		1	1867	33.5	9	13.5	medium/large	0.70	10.5	pinched
7-110	old box	wet streambed	0.01		1	8166	60.24	5.5	5	small	0.52	15.8	fragmented
73-5	span	level floodplain	0.00		1	1400	32.2	5	235	medium/large	1.19	9	diffuse
9-25a	span	level floodplain	0.01		2	3885	42	20	293	medium/large	3.02	30	diffuse
9-25b	span	level floodplain	0.00		2	3885	42	20	276	medium/large	2.84	30	diffuse
I91-101-2s	pipe culvert	round pipebottom	0.00		1	4802	38	7	7	small	0.79	19	diffuse
I91-101-3s	pipe culvert	round pipebottom	0.00		1	4802	104	6	6	small	0.47	15	diffuse
i91-17-2	V bottom box	dry concrete	0.00		2	16562	235	8	10	medium/large	0.60	20	pinched
I91a	pipe culvert	round pipebottom	0.00		1 and 2	4802	190	5	5	small	0.77	43	diffuse
I91bE	pipe culvert	round pipebottom	0.00		1	4802	228	5	5	small	0.81	38	diffuse
I91bW	pipe culvert	round pipebottom	0.00		1	4802	180	5	5	small	0.81	25	diffuse
union st	span	even streambank	0.00		2	356	27	10	136	medium/large	0.71	12	pinched

Appendix B: Select game camera photos

Bobcat at *squash pipe* in Sunderland, VT (Site 7-19-5)

Bobcat at *pipe culvert* in Manchester (Site 7-19-5)

Deer at entrance to I91- in Putney (*V bottom box culvert*). Did not enter the structure.

Bear moving under *span* 4-42, Bridgewater

Bears moving under *span* 9-25a, Searsburg

Bobcat moving under *span* 133-13, Ira

Bobcat moving through *pipe culvert* 16-13, Glover

Bear entering *arch culvert* 17-24, Starksboro

Fisher at *pipe culvert* 155-6, Mt Holly

Fisher at site 7-23-8, Manchester

A pair of bobcats at Union St *span* over Otter Creek, Brandon

Coyote at *span* 100a-8, Plymouth

Coyote at *new precast box culvert* 100-47, Wilmington

Fisher at *span* 113-19, Vershire

Fisher at *old box culvert* 122-24, Glover

Skunk at Union Street *span*, Brandon

Mink at Union Street *span*, Brandon

Bobcat at *squash pipe* 7-19-5, Sunderland

Bobcat at *span* at Union Street, Brandon

Bears at *span* 9-25b, Searsburg

Deer at *span* at Union Street, Brandon

Bobcat at *new precast box culvert* 125-19, Ripton (only through-passage recorded for this site)

Fox approaching *pipe culvert* 9-17, Woodford (did not enter)

Bobcat at *pipe culvert* I91a, Sheffield

Ermine at *pipe culvert* 155-6, Mt Holly

Bald eagle at *span* 9-25b, Searsburg

Moose tracks crossing US 4 near *span* 4-42, Bridgewater

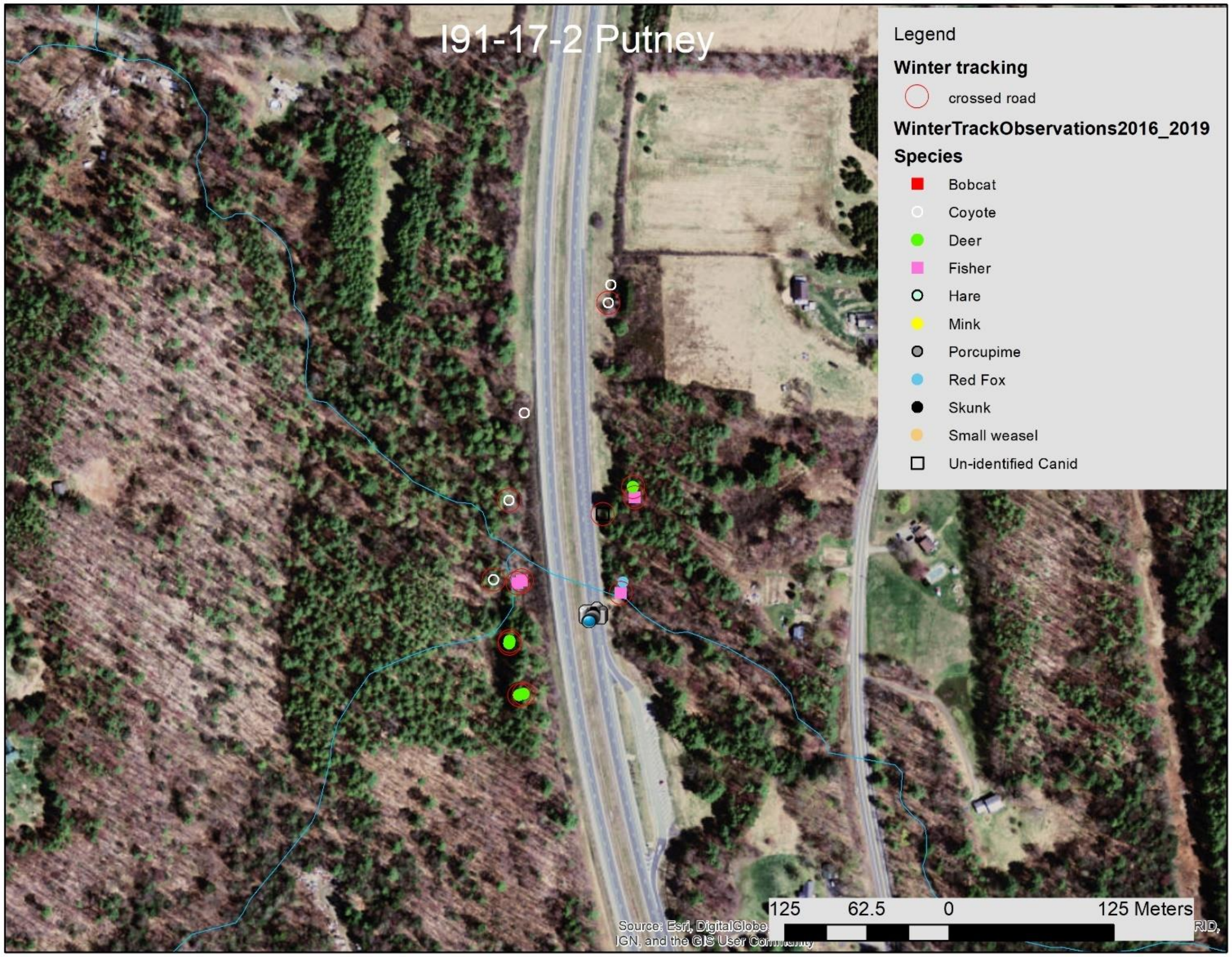
Moose tracks on US4 pulloff near *span* 4-42, Bridgewater

Appendix C: Structure design, movement surface, and wildlife use characterization table

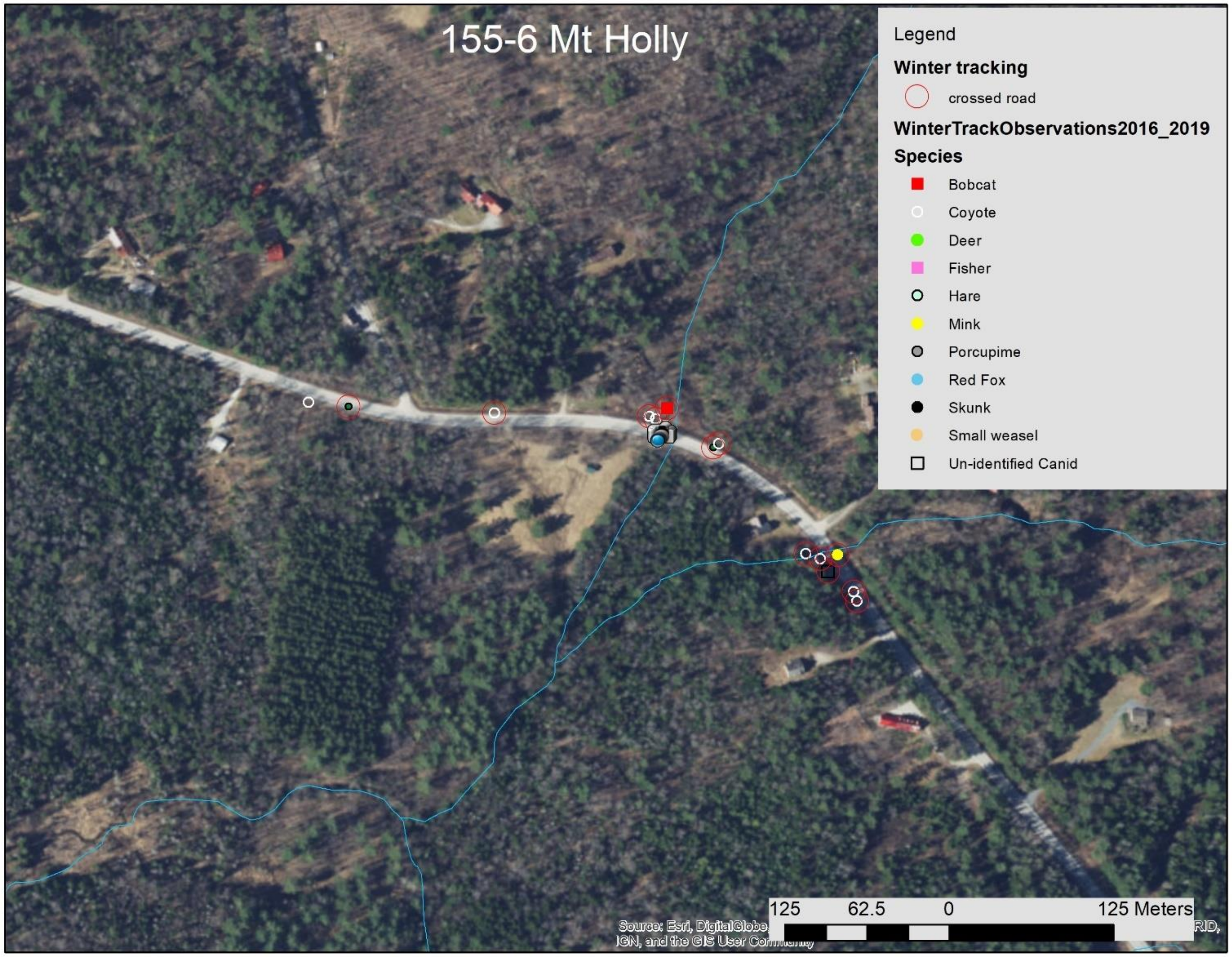
structure design type	**movement surface category**	**substrate**	**relationships between design and movement surface**	**use**
arch culvert	dry or partially dry natural streambed	natural - goverend by hydrology (silt/sand/gravel/cobble/boulder)	will have dry movement surface unless structure is undersized	movement through stream channel - dry if structure is large enough. Usable by bobcat, deer, bear, some bear use, and if large enough, coyote
old box culvert	sheetflow concrete	almost always concrete, unless its embedded enough for retainment of silt/sand/gravel, etc)	flat concrete structure bottoms always wet - only dry if stream is annual.	little to no wildlife use unless stream is annual (dries up periodically)
"V" bottom box culvert	dry concrete		dry concrete along edges of culvert bottom	movement along dry concrete edges of structure.
new precast box culvert	dry gravel/sand/cobble streambank	dry gravel/sand/cobble streambank	low/moderate gradient stream	gradient low enough and structure wide enough for deposition of finer particles on culvert margins, forming dry movment surfaces. The finer, the better. All sites studied were new with de-vegetated surroundings from construction, so animal use data not available Hypthetically good for species accordinng to size/movement guild relationships
	dry boulder/cobble	dry boulder/cobble deposited along culvert bottom	high gradient stream	may be designed with baffles to retain boulders/cobbles. Requires a "rock hop" type of passage that most species (especially deer) will choose to avoid.
pipe culvert	round pipebottom	corrugated metal	will have dry movement surface unless structure is undersized	substrate curved corrugated pipebottom, use usually restricted to weasels and bobcat
squash pipe	flat pipebottom	corrugated metal	will have dry movement surface unless structure is undersized	use typically restricted to weasels and bobcat
span	riprap bank	large riprap	bank stabilization used under a majority of bridge spans	used preodminatly by weasels, bobcat, and coyote, and sometimes bear. weasels less often because of their preference for cover
	even streambank	some combination of silt/sand/gravel/cobble	from fine, fluvial-deposited sediment; low gradient rivers wher bank stabilization not needed	use by deer and bobcat and weasels. Coyote if wide enough. potentially bear, moose
	dry streambed	some combination of silt/sand/gravel/cobble	driven by stream hydrology: abnormally flashy streams with periods of no flow	deer, bobcat, coyote, weasels observed, potentially bear, moose
	level floodplain	depends on river system - from silt (Otter Creek) to gravel/cobble/boulder (Deerfield River)	predominantly fine particle substrate; typically found under valley-spanning bridges	used predominantly by deer and coyote, with bear, some bobcat, and moose potential
span with concrete footing shelf	dry concrete	dry level concrete	footings built on shallow ledge offer flat dry movment surfaces at most river flows	used predominantly by bobcat, with some use by weasels

Appendix D: Site Maps with Tracking Data

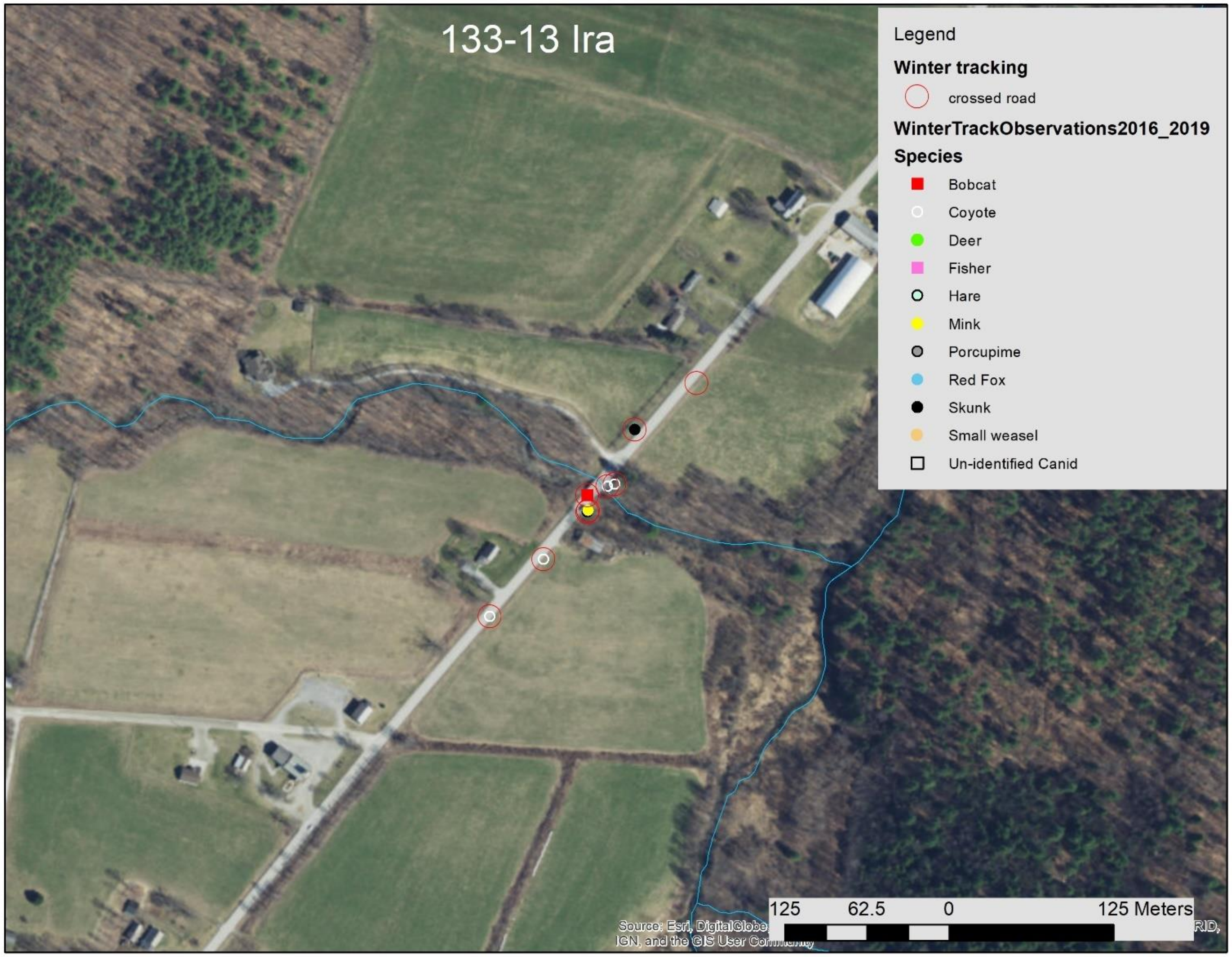
Source: Esri, DigitalGlobe, ... RID, IGN, and the GIS User Community



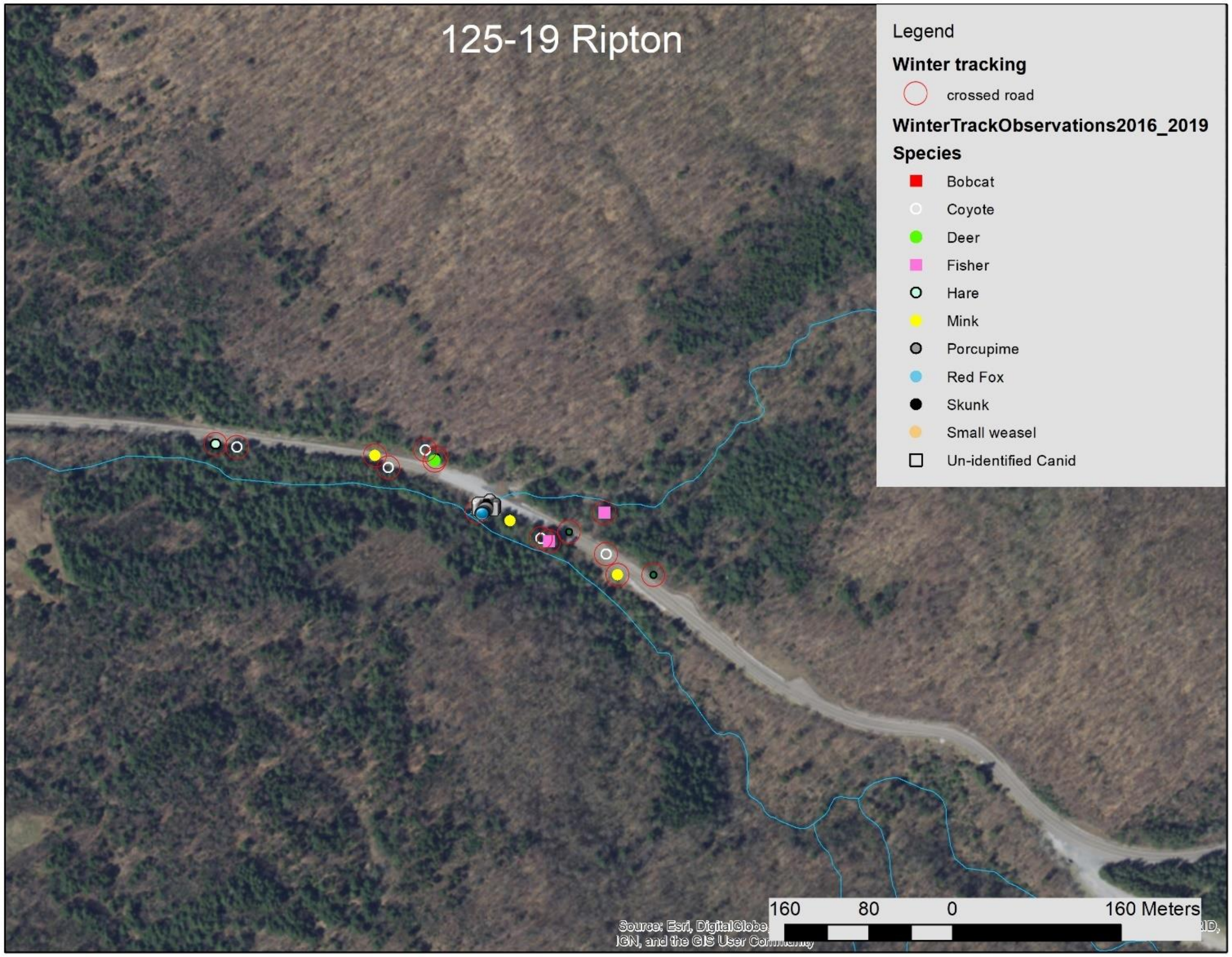
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

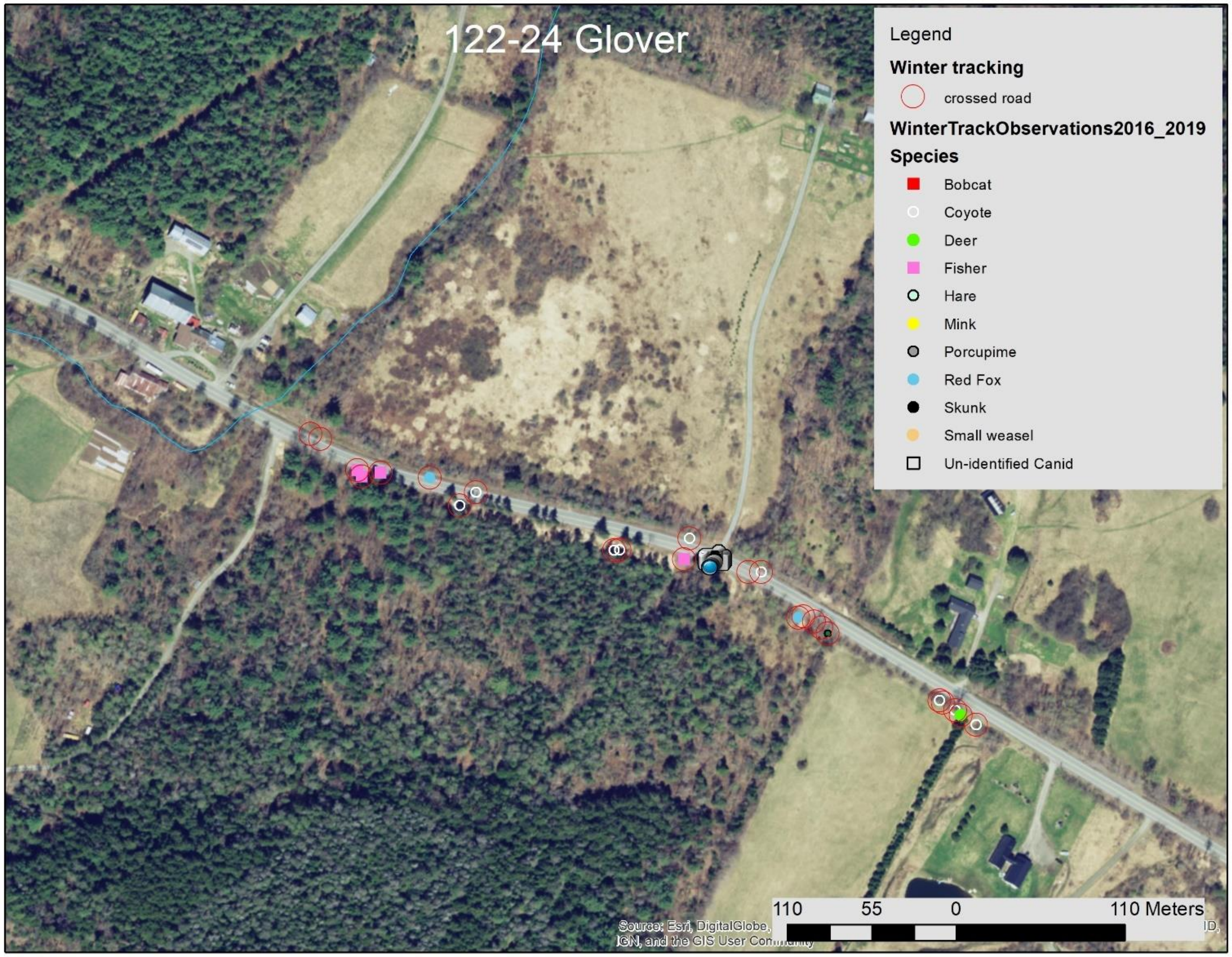


Source: Esri, DigitalGlobe, RID,
IGN, and the GIS User Community

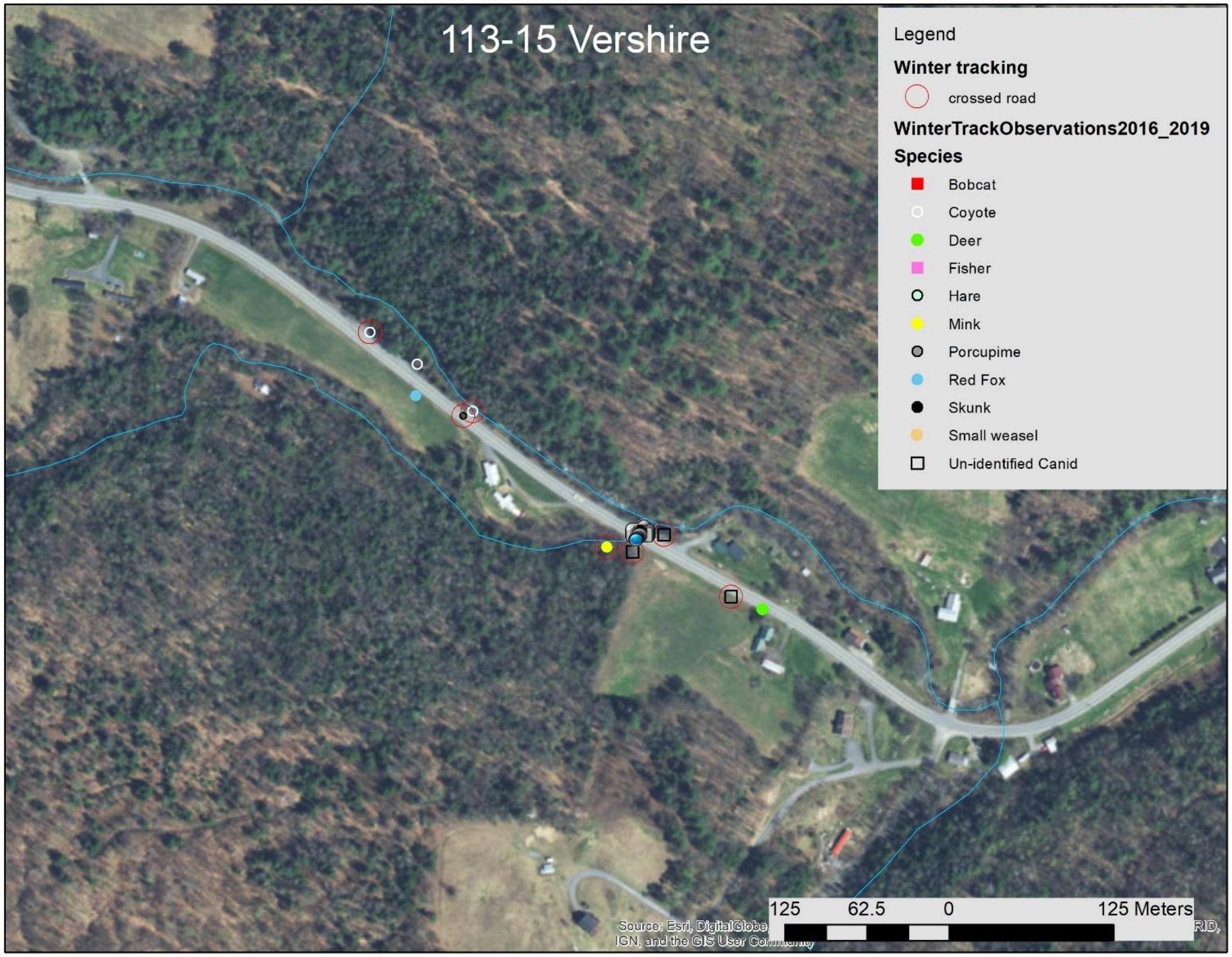


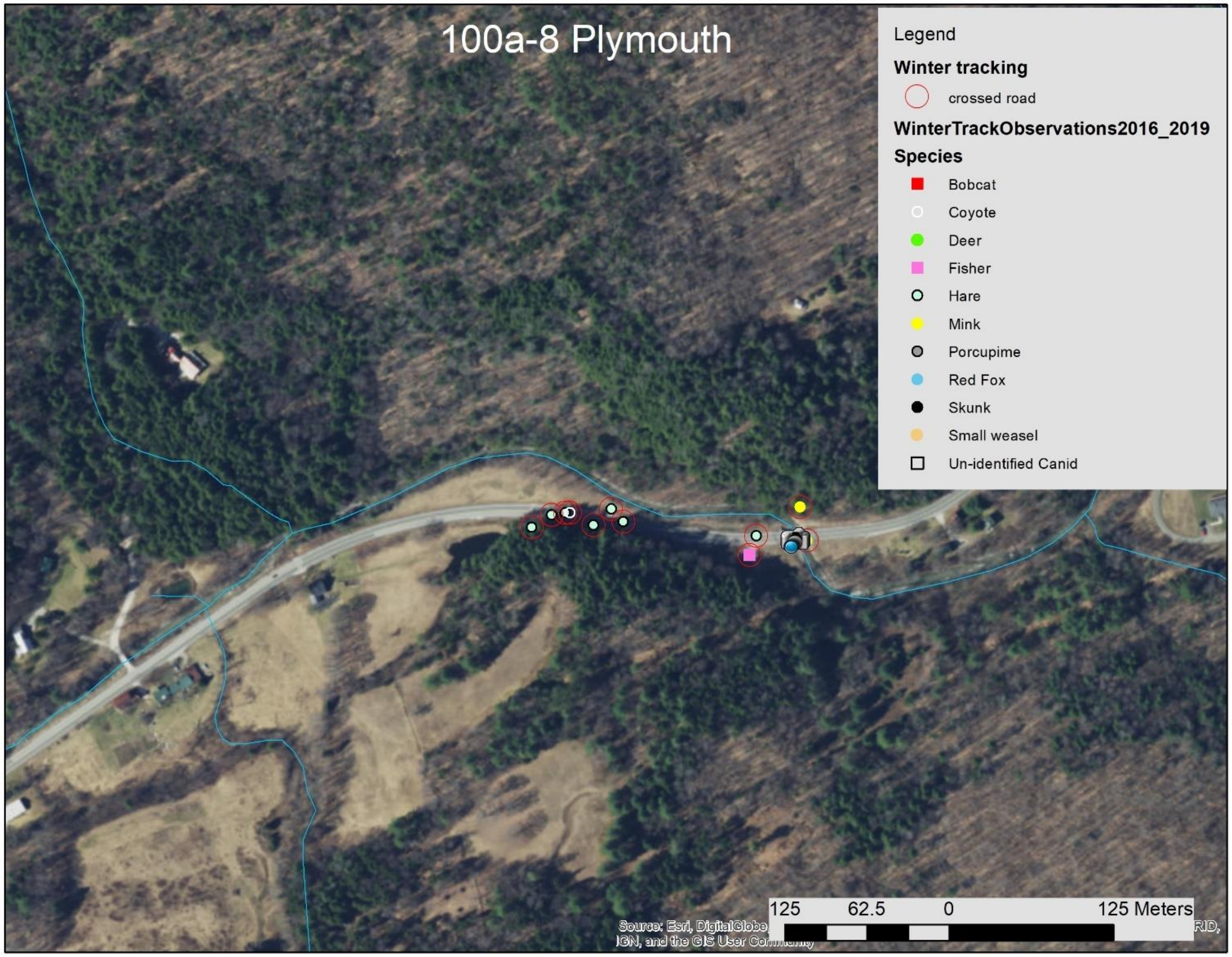
Source: Esri, DigitalGlobe RID, IGN, and the GIS User Community

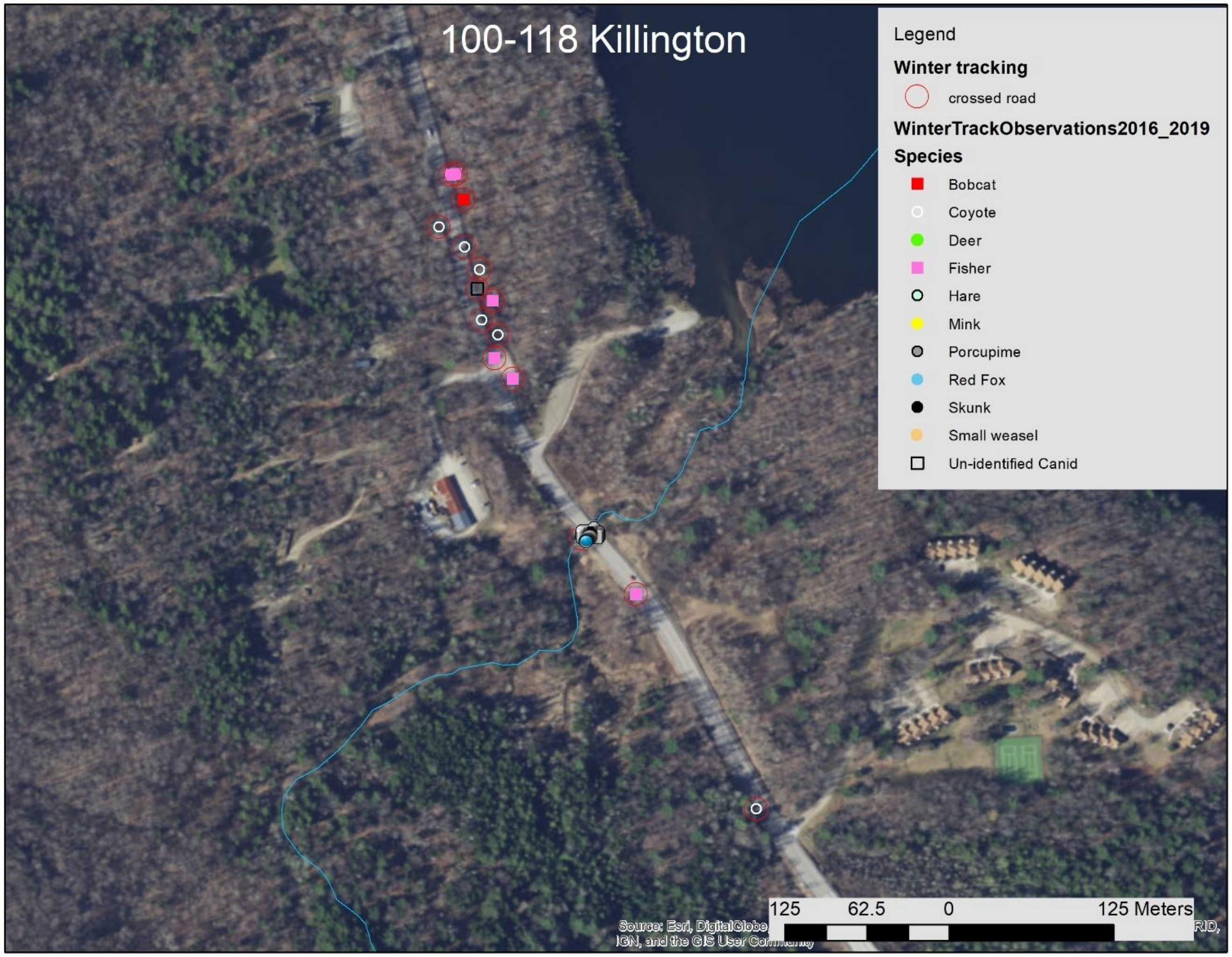

125-19 Ripton
Legend
Winter tracking
○ crossed road
WinterTrackObservations2016_2019
Species
■ Bobcat
○ Coyote
● Deer
■ Fisher
○ Hare
● Mink
● Porcupime
● Red Fox
● Skunk
● Small weasel
☐ Un-identified Canid
160
80
0
160 Meters
Source: Esri, DigitalGlobe
IGN, and the GIS User Community

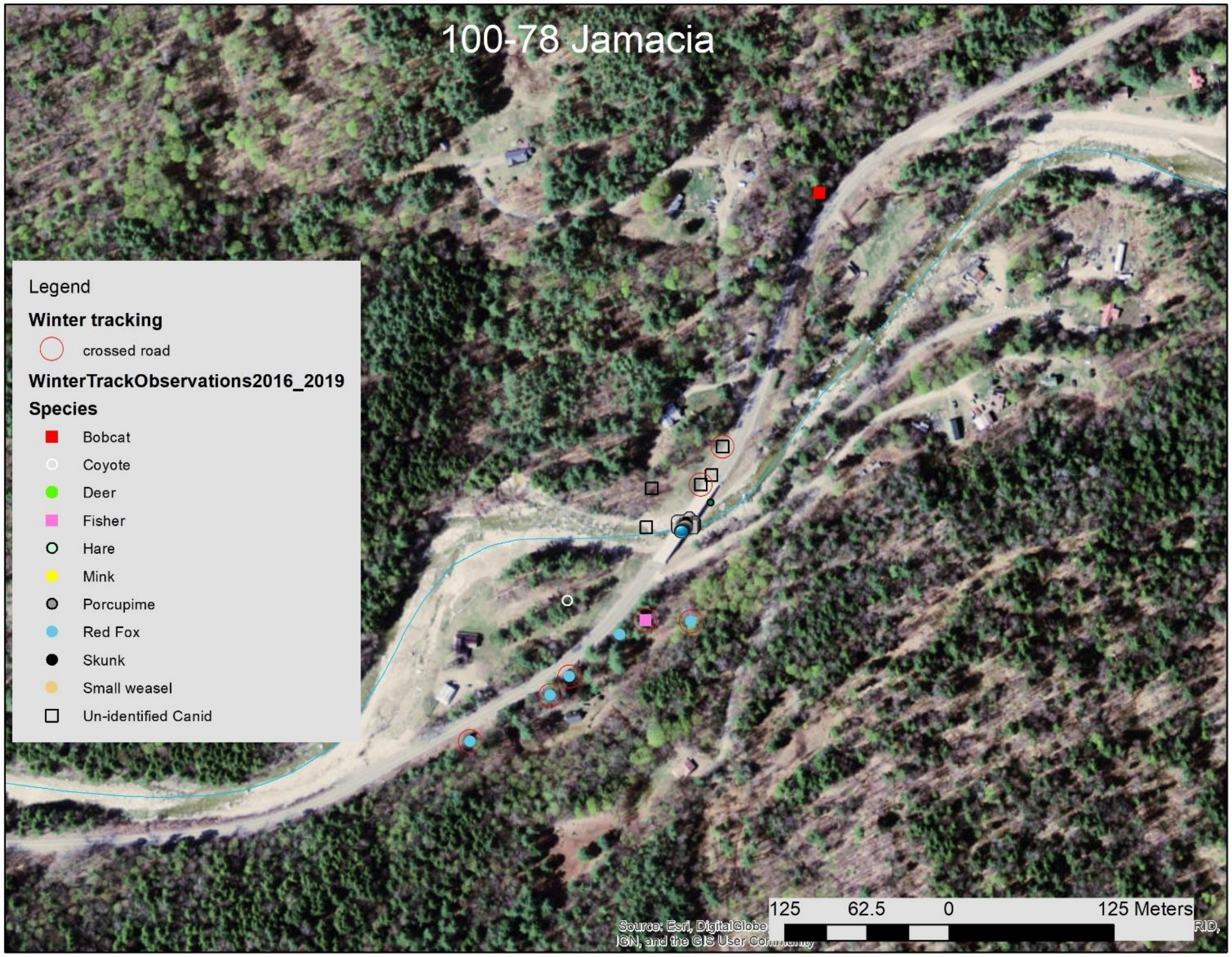

122-24 Glover
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
110
55
0
110 Meters
Source: Esri, DigitalGlobe,
IGN, and the GIS User Community


113-19 Vershire
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

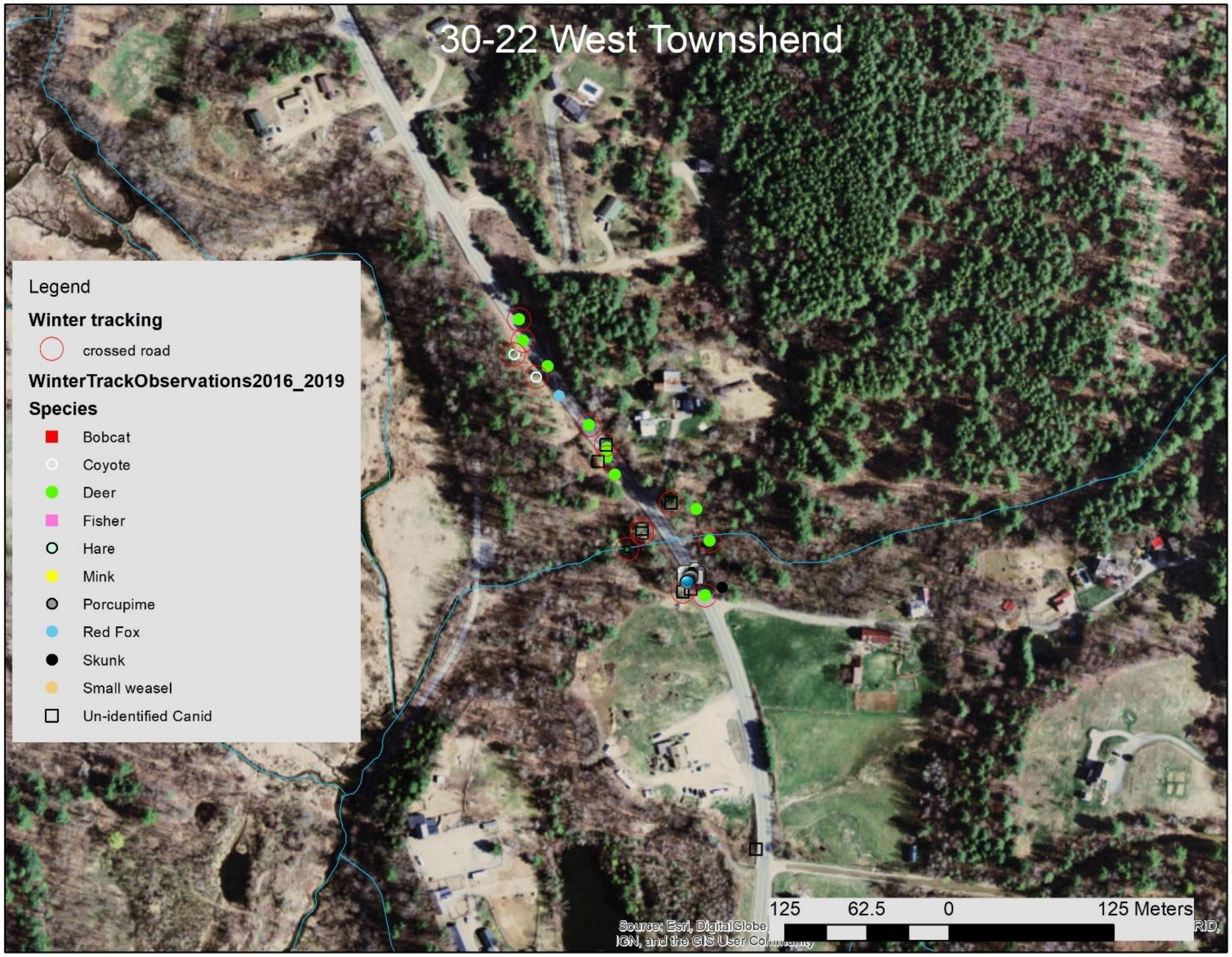

113-15 Vershire
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

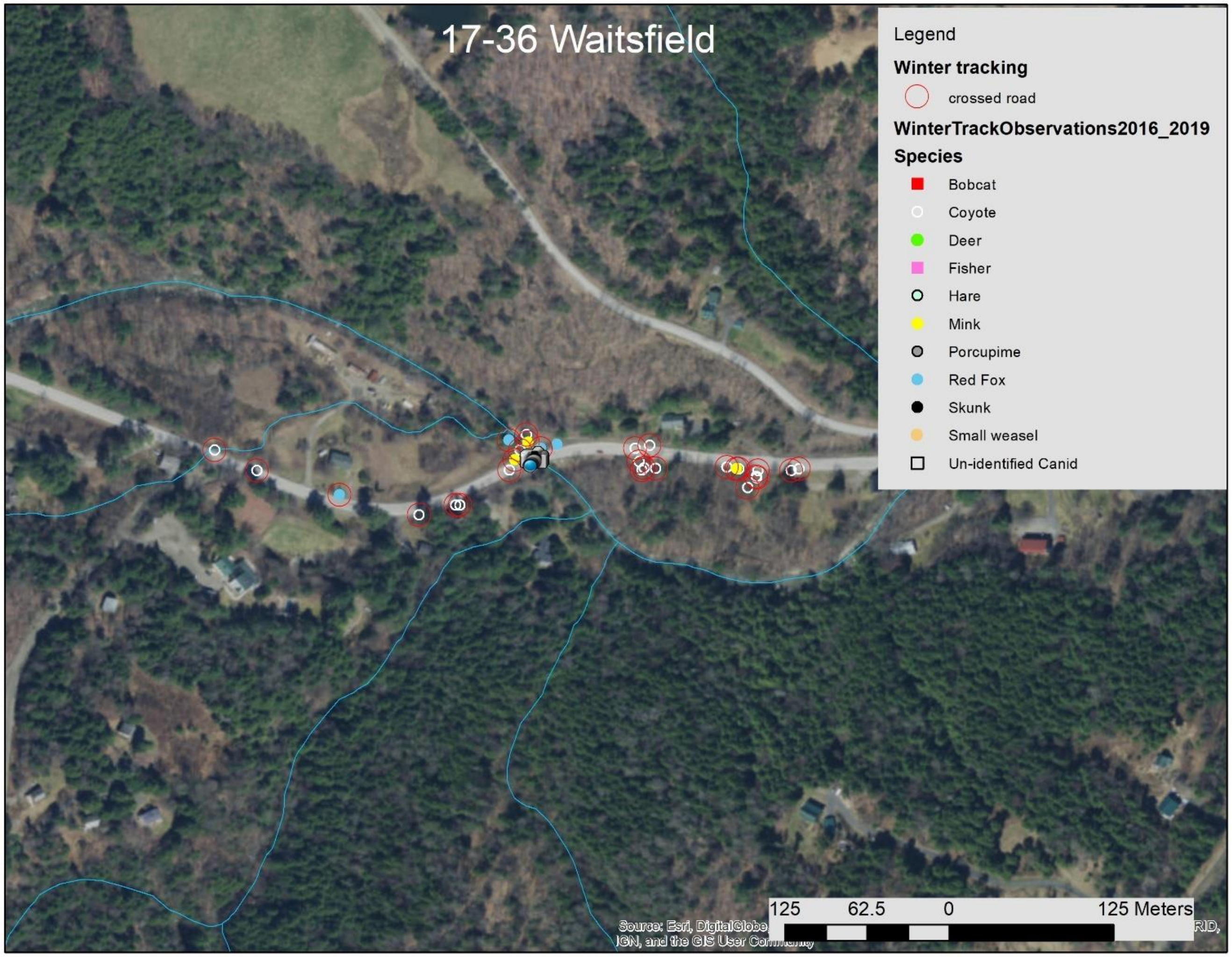

100a-8 Plymouth
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

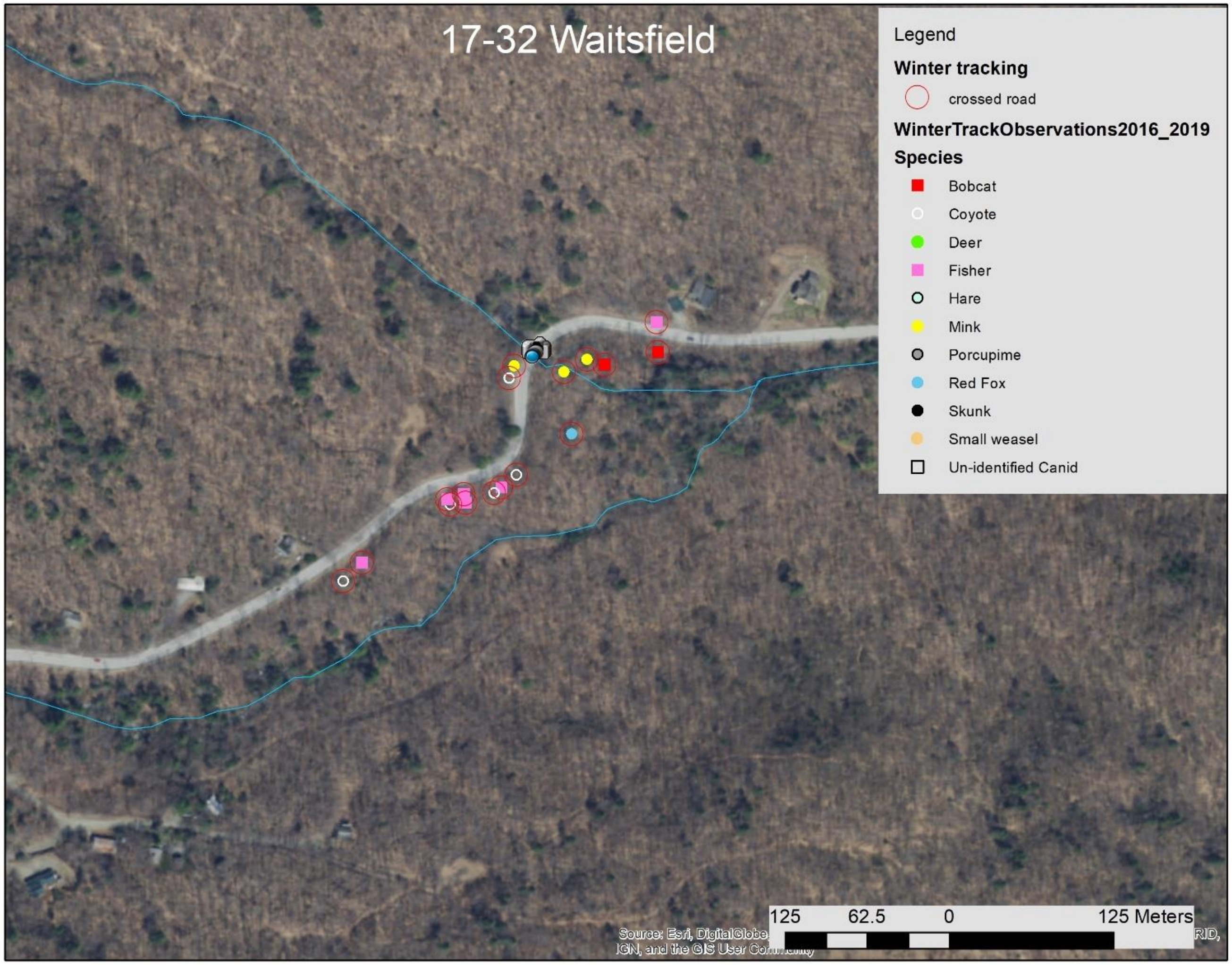

100-118 Killington
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125 62.5 0 125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

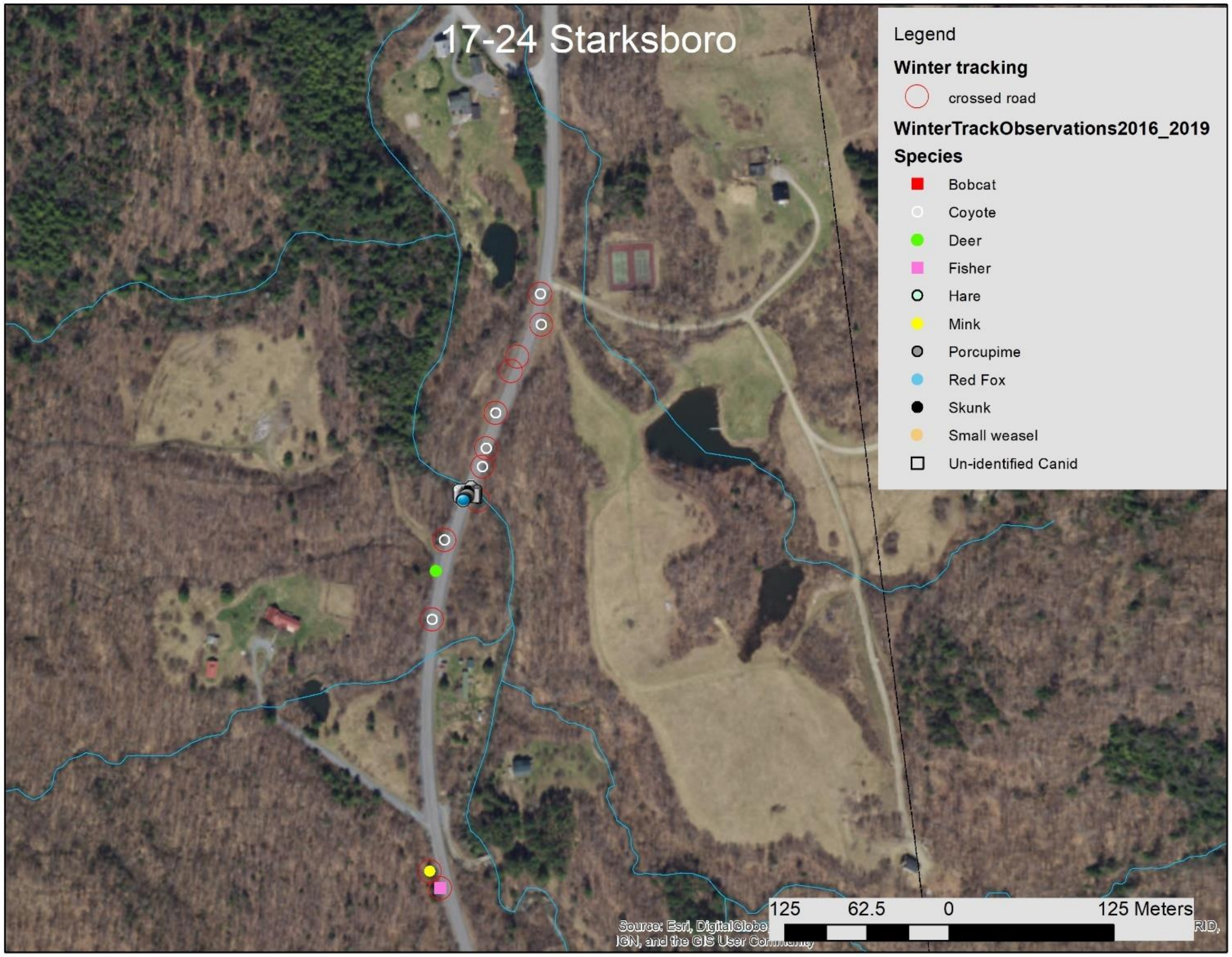

100-78 Jamacia
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

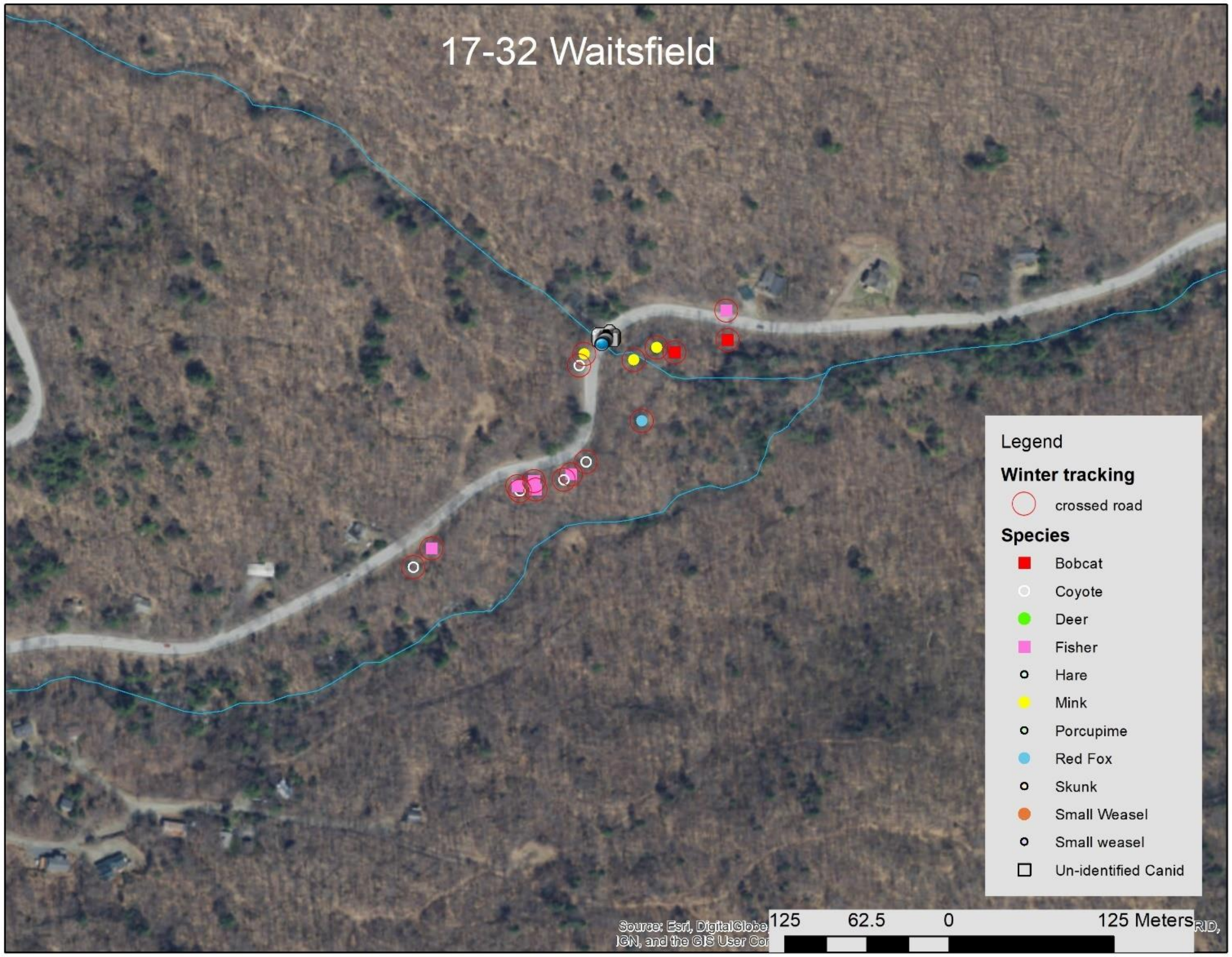
Source: Esri, DigitalGlobe ID, IGN, and the GIS User Community


30-22 West Townshend
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
IGN, and the GIS User Community
RID,

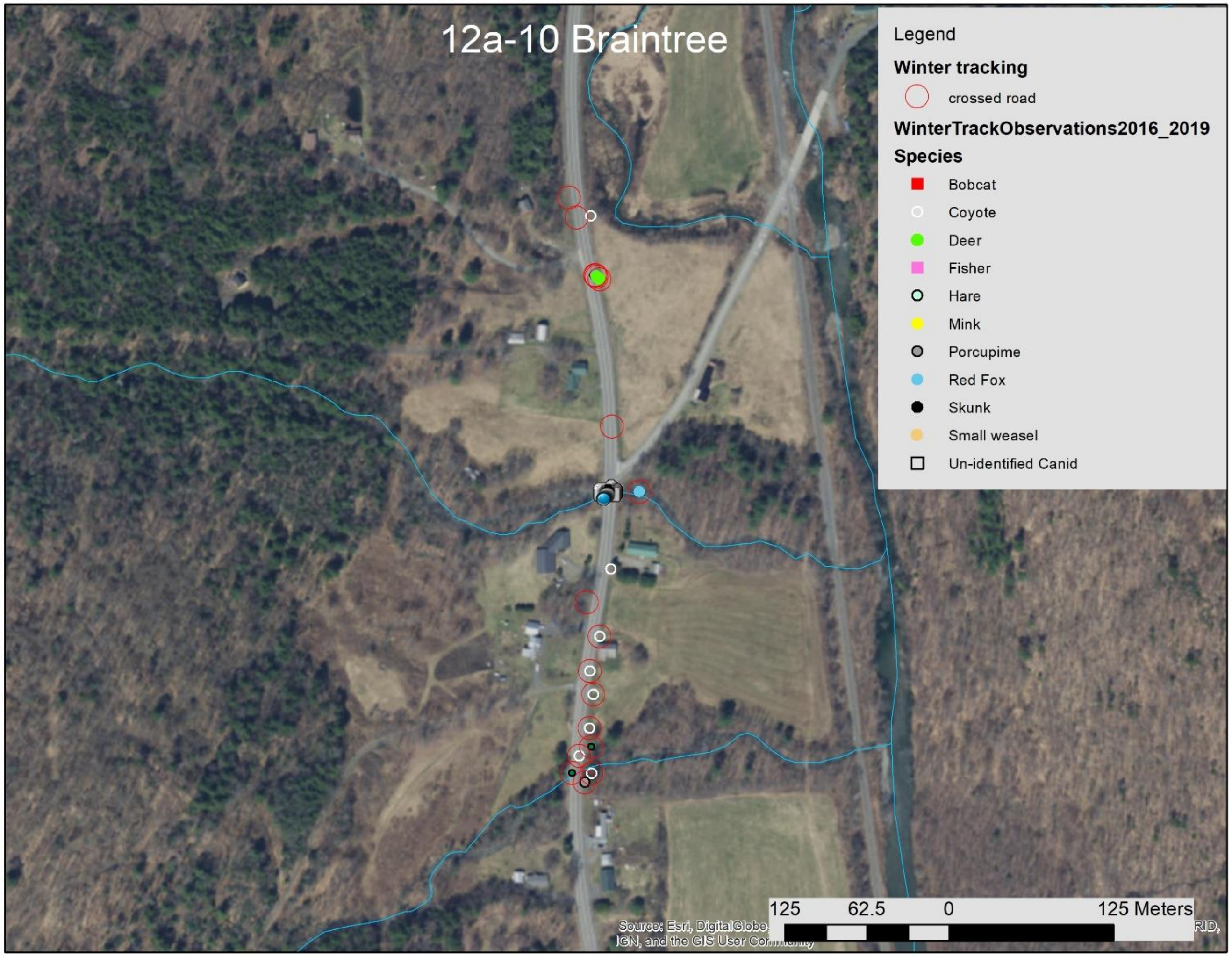

17-36 Waitsfield
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community


17-32 Waitsfield
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

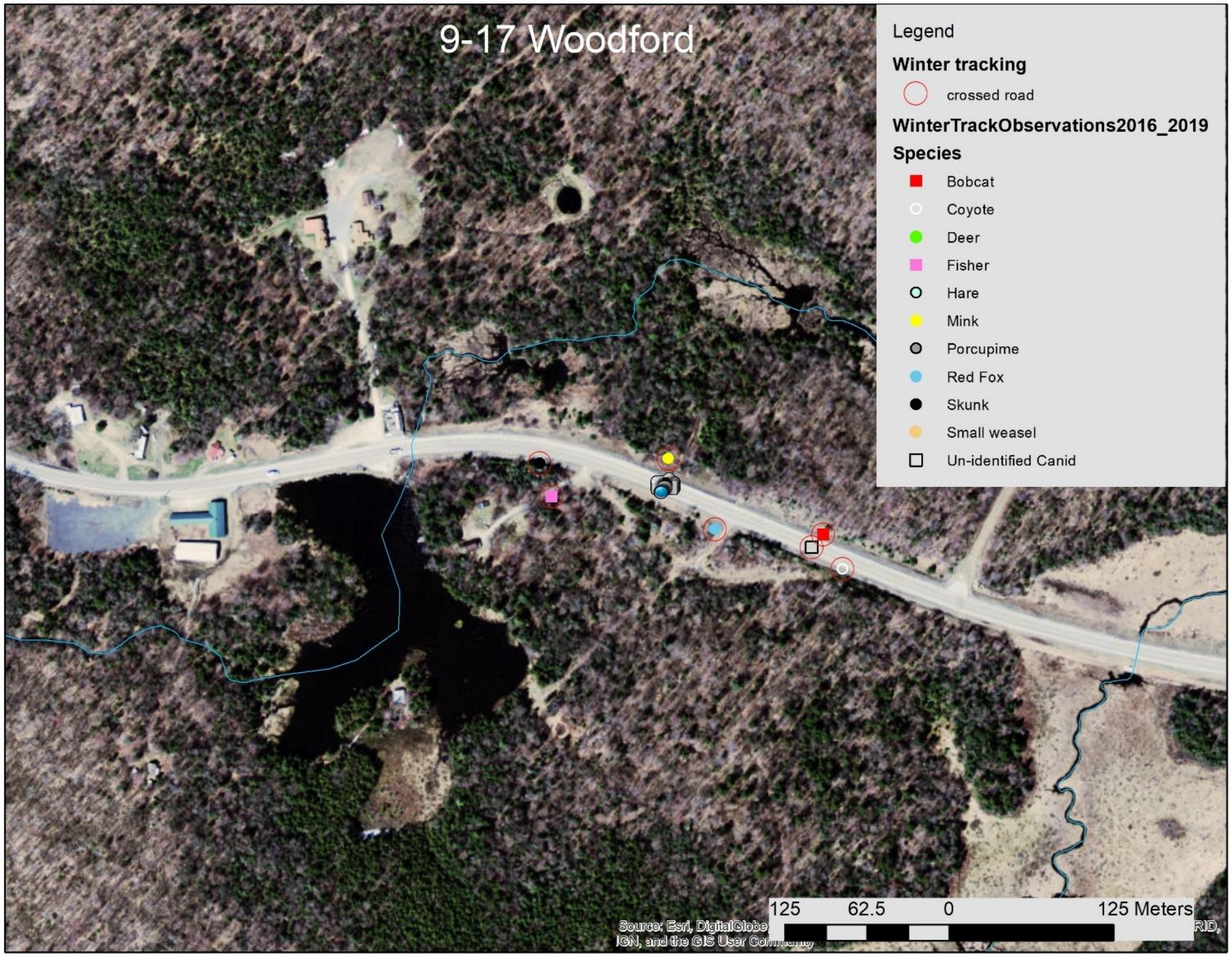

17-24 Starksboro
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125 62.5 0 125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

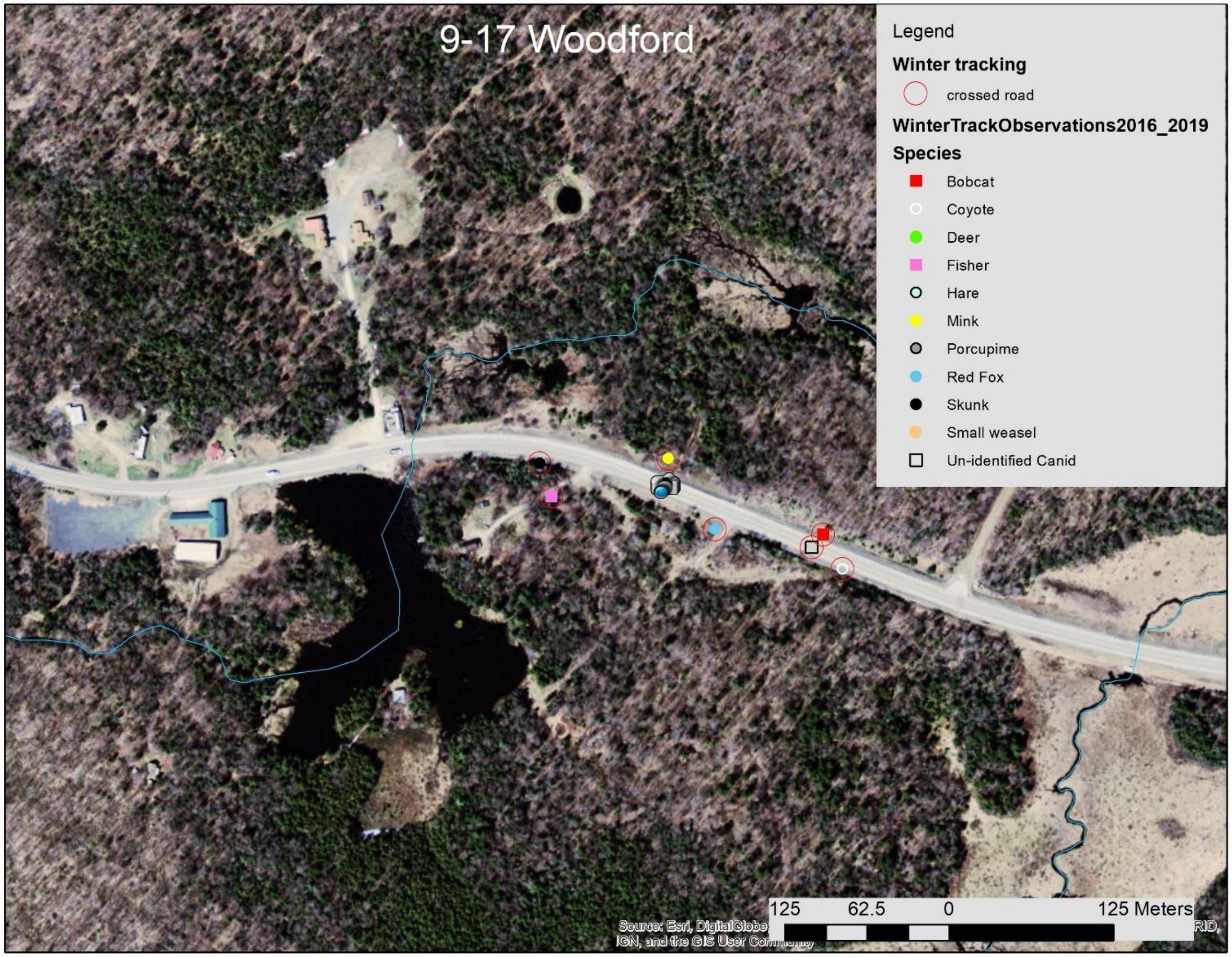

17-32 Waitsfield
Legend
Winter tracking
crossed road
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small Weasel
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
IGN, and the GIS User Co
RID,


16-13 Glover
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125 62.5 0 125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

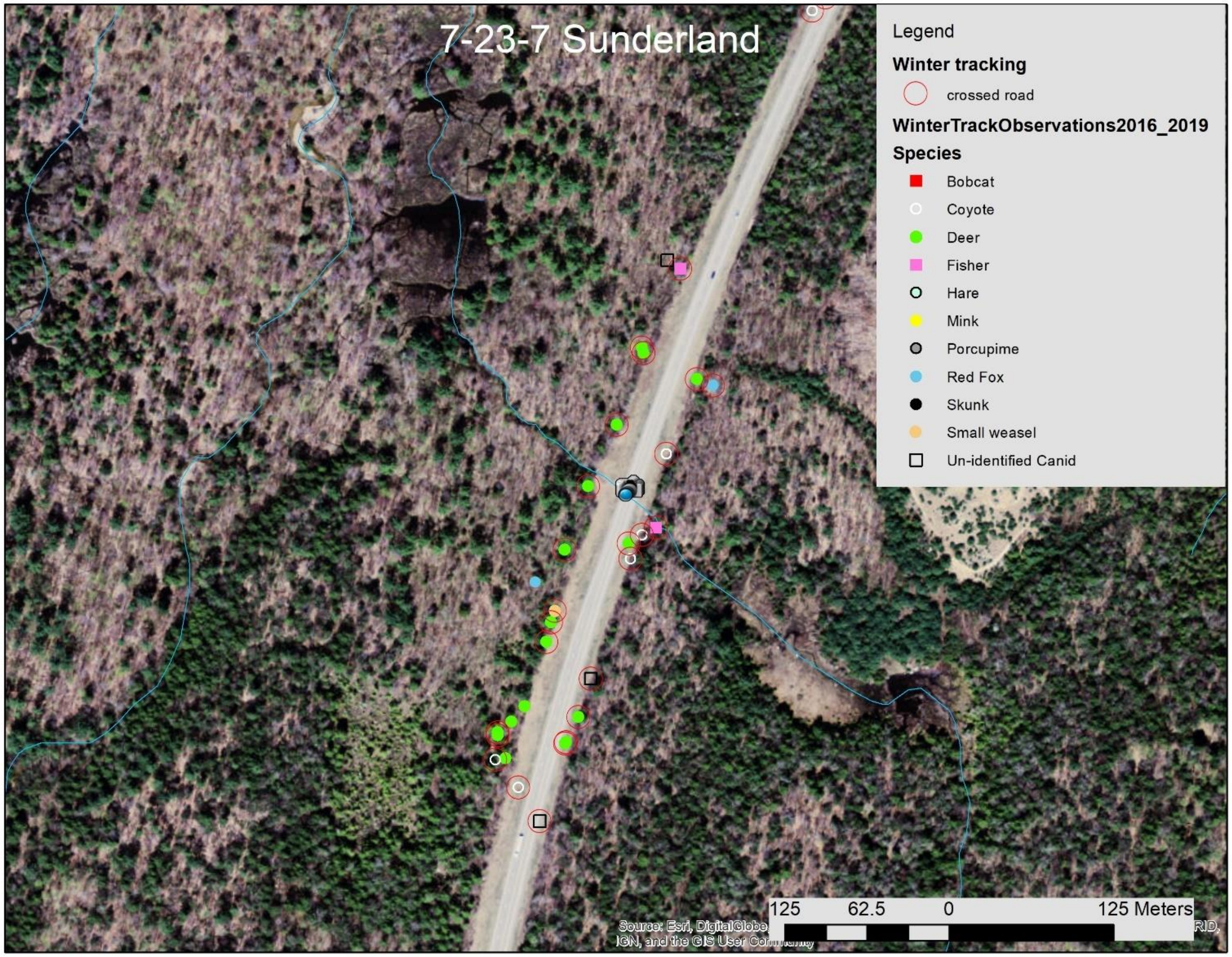

12a-10 Braintree
Legend
Winter tracking
○ crossed road
WinterTrackObservations2016_2019
Species
■ Bobcat
○ Coyote
● Deer
■ Fisher
○ Hare
● Mink
● Porcupime
● Red Fox
● Skunk
● Small weasel
☐ Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
IGN, and the GIS User Community
RID,


9-25 a & b Searsburg
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
GN, and the GIS User Community
RID,

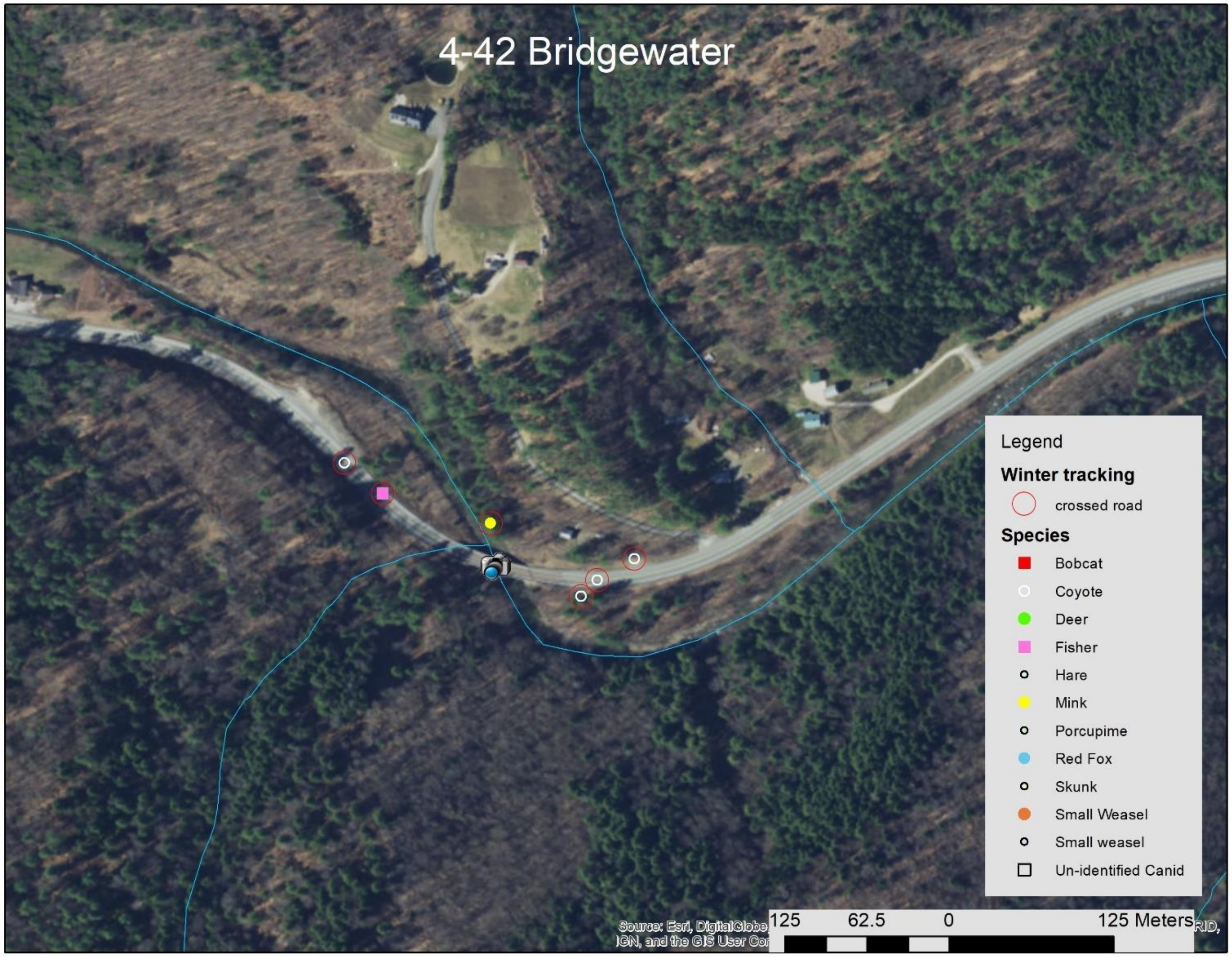

9-17 Woodford
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
IGN, and the GIS User Community
RID,



Source: Esri, DigitalGlobe, RID,
IGN, and the GIS User Community


7-23-7 Sunderland
Legend
Winter tracking
crossed road
WinterTrackObservations2016_2019
Species
Bobcat
Coyote
Deer
Fisher
Hare
Mink
Porcupime
Red Fox
Skunk
Small weasel
Un-identified Canid
125
62.5
0
125 Meters
Source: Esri, DigitalGlobe
RID,
IGN, and the GIS User Community

Source: Esri, DigitalGlobe RID,
IGN, and the GIS User Community


4-42 Bridgewater
Legend
Winter tracking
○ crossed road
Species
🟥 Bobcat
○ Coyote
● Deer
■ Fisher
○ Hare
● Mink
○ Porcupime
● Red Fox
○ Skunk
● Small Weasel
○ Small weasel
☐ Un-identified Canid
125 62.5 0 125 Meters
Source: Esri, DigitalGlobe
IGN, and the GIS User Co
RID,