American marten occupancy and habitat associations using a camera trap array in the Northern Lower Peninsula, Michigan

2021 – 2022 Survey Effort

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Cover Photo(s): American marten photographed on remote camera traps during this survey.

Acknowledgements

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Abstract

American martens (*Martes americana*) are a small forest carnivore of high ecological and cultural value in Michigan. They are indicators of ecological integrity due to their close association with late-successional forests with structurally complex woody features that support numerous wildlife species. Therefore, ensuring their viability on the landscape demands explicit action by forest management and conservation decision making to sustain and promote these forest conditions where martens occur or are likely to occur. Since 2020, the Little Traverse Bay Bands of Odawa Indians have been surveying state forest lands throughout the northern Lower Peninsula (NLP) of Michigan using a remote camera trap survey grid. Our objectives were to: (1) use a grid-based remote camera trap survey to estimate site occupancy of martens that leverages information gained from previous survey efforts, (2) predict relationships between site occupancy and habitat characteristics, and (3) provide these data and estimates to help inform wildlife and forest management practices for the improvement of marten and fisher population viability on state forest lands in the NLP. Surveys in 2021 and 2022 have expanded our knowledge of the spatial distribution of marten occurrences on state forest lands and enhanced our understanding of fine-scale distribution and habitat associations in previously surveyed regions. We deployed 75 passive infrared camera traps in 2021 and 70 camera traps in 2022 within state forest lands of the Emmet Moraines, Wolverine Moraines, Huron Sandy Lake Plain, and Presque Isle Lake and Till Plains FRD management areas. Martens were detected at the most camera trap sites within the Chandler Hills (2021) study area, followed by the Jordan River study area (2022), both within the Wolverine Moraines. From camera trap data we estimated site occupancy and habitat associations using single-season occupancy models within a model selection framework to evaluate the influence of dominant land cover classes on marten occupancy probability. The proportion of upland deciduous forest (i.e., northern hardwood) surrounding camera trap sites continued to be the most significant positive predictor of marten occupancy throughout the study area, and the abundance of coarse woody debris surrounding a camera trap site was a positive predictor of marten detection probability, but was only significant in the 2021 survey. Although marten appear to be persisting under the current management regime based on our surveys and others, preliminary evidence from our survey in the Wolverine Moraines suggest marten are detected less in areas with proportionally greater acreage under clearcut or select cut methods. We encourage harvest treatments and forest management plans to implement the marten occurrences learned from these survey efforts to help further inform and adapt silvicultural treatments to mitigate marten habitat loss and ensure occupied and unoccupied suitable habitat remains interconnected.

American marten at camera 70 on state forest land in the Chandler Hills study area of the Wolverine Moraines FRD Management Area.

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Introduction

American martens (*Martes americana*; hereafter marten) are a small forest carnivore generally associated with late-successional upland deciduous or coniferous forests having high canopy closure (> 50%) and complex physical structure near the ground (Buskirk and Powell 1994, Dumyahn et al. 2007). Their presence serves as an indicator of ecological integrity in forested systems (McLaren et al. 1998) and are culturally significant as a clan animal (Wabizhashi Dodem) to the Anishinaabek. They were reintroduced to Michigan's Northern Lower Peninsula (NLP) in the mid-1980s following extirpation due to habitat loss and overexploitation during the late 19th and early 20th century and were protected as a State Threatened species until 1999 (Earle et al. 2001, Williams et al. 2007). Reintroduction efforts took place in two distinct landscapes, the Pigeon River Country State Forest and the Manistee National Forest/ Pere-Marquette State Forest, which are separated by about 150 km of land fragmented by agriculture, highways, and urban areas. Harvest is currently banned in the NLP where they are designated as a Regional Forester's Sensitive Species by the National Forest System (USDA Forest Service 1996) and a Featured Species by the Michigan Department of Natural Resources (MDNR; MDNR 2016). Marten populations in the NLP occupy a landscape dominated by upland deciduous forests and as such, their habitat associations have differed considerably from populations in other regions (Buskirk and Powell 1994, Ruggiero et al. 1994). Several studies have begun to improve our understanding of marten distribution, ecology, and habitat use in the NLP (Buchanan 2008, Williams and Scribner 2010, Nichols 2016, Sanders et al. 2017, Gehring et al. 2019, Wilton 2021). For example, Gehring et al. (2019) estimated that < 25% of the NLP may contain primary marten habitat and was mostly comprised of habitat patches that are smaller (i.e., < 1,000 ha) and isolated. Occupancy and population persistence of these patches may rely on the interconnectedness among suitable patches (Howell et al. 2016) and studies have indicated loss of genetic diversity in the NLP population resulting from a small founding population size and limited natural dispersal due to these isolated habitat conditions (Watkins 2012, Hillman et al. 2017).

The effects of forest fragmentation and conversion on the persistence of marten populations have been well documented in the scientific literature (Chapin et al. 1998, Moriarty et al. 2011, Koen et al. 2012, Happe et al. 2019, Gurtler 2020). Numerous studies suggest martens may be sensitive to forest management that degrades or reduces fine-scale habitat features (e.g., coarse woody debris [CWD], snag trees) required for foraging, denning, resting, and escape cover (Proulx 2021). Monfils et al. (2011) found that managed northern hardwood and aspen stands in Michigan had significantly less large diameter and highly decayed CWD than in unmanaged forests. Much of the potential marten and fisher habitat in the NLP, and specifically within the 1855 Little Traverse Bay Bands of Odawa Indians (LTBB) Reservation, occurs on managed state forest land that is subject to varying forest and wildlife management goals. The MDNR designates numerous highly valued wildlife species as Featured Species, where each designated species faces certain habitat problems for which solutions can be addressed through management actions (MDNR 2013). Marten are designated as a Featured Species within 8 of the 33 Forest Resources Division (FRD) management areas, mostly concentrated around the marten reintroduction sites. Marten habitat management within these focal Management Areas prioritizes increasing available habitat through management actions that maintain and improve contiguous tracts of mature forest that contain

the ecological characteristics necessary to meet marten life history requirements. These requirements also contribute to the habitat needs of fishers and 13 additional Featured Species (MDNR 2013).

In the NLP where marten harvest data are not available (Frawley 2019), evaluation of population status and conservation priorities relies on other direct or indirect survey methods (Fuller et al. 2016). Early efforts to monitor the NLP marten population used a combination of sightings and sign, bait station track surveys, winter track survey routes, habitat assessments, and live-trapping (Earle et al. 2001). Most current studies in the NLP used live-trapping and radiotelemetry to study various aspects of marten ecology, including den and rest site characteristics (Nichols 2016, Sanders and Cornman 2017), genetic diversity (Hillman et al. 2017), home range and resource use (Buchanan 2008), and regional habitat suitability (Gehring et al. 2019). Other methods to monitor marten populations in the NLP have included remote camera traps to estimate occupancy probability and detection probability, dietary needs, and denning ecology (Nichols 2016, Root 2020, Wilton 2021, Little River Band of Ottawa Indians [LRBOI] *unpublished data*[1]). Hair snares and scat detection dogs have also been used to collect genetic samples for determining marten and fisher presence and understanding marten population genetics (Watkins 2012, LTBB *unpublished data*).

Although several studies and monitoring efforts have tracked marten population status and predicted suitable habitat in the NLP, many areas still lack formal surveys to validate marten occupancy and detecting potential range expansion from source populations remains a critical challenge. Moreover, evidence of fisher populations is supported only by anecdotal and incidental observations. We expand on initial efforts to survey marten populations (Wilton 2021) on state forest lands within the 1855 LTBB Reservation (hereafter Reservation) and adjacent landscape of the NLP. The LTBB have documented the presence of both martens and fishers within its Reservation on private and public lands (Bill Parsons, LTBB Natural Resources Department [NRD], *unpublished data*). Given the ecological and cultural value of martens and fishers to the region, improving understanding of these populations is important for informing forest management practices and predicting how associated landscape changes may affect marten population distribution and viability in the NLP. Our objectives were to: (1) use a grid-based remote camera trap survey to estimate site occupancy of martens that leverages information gained from previous survey efforts, (2) predict relationships between site occupancy and habitat characteristics, and (3) provide these data and estimates to help inform wildlife and forest management practices for the improvement of marten population viability on state forest lands in the NLP.

Methods

Study Area

We conducted this survey on state forest lands in the Northern Lower Peninsula (NLP), Michigan within Antrim, Charlevoix, Cheboygan, Emmet, Otsego, and Presque Isle County, including the 1855 LTBB Reservation). This area occurs within the MDNR Gaylord and Atlanta Forest Management Units (FMU), including the Emmet Moraines, Wolverine Moraines, Huron Sandy Lake Plain, and Presque Isle Lake and Till Plains FRD management areas (Figure 1). These management areas are ≤ 50 km from marten reintroduction sites in the Pigeon River Country State Forest. State forests are managed for various recreational, silvicultural, and ecological objectives (MDNR 2013). Timber extraction is the primary silvicultural treatment on state forest lands but is spatially variable in intensity.

Housing density decreases sharply away from city centers along the Lake Michigan shoreline and Interstate-75, with much of the landscape dominated by upland forest (52% of land cover), lowland forest (15%), agriculture (6%), and open water (15%) land cover (see Figure 2 map inset for area used to summarize land cover types). Upland forests are characterized by northern hardwoods (dominated by

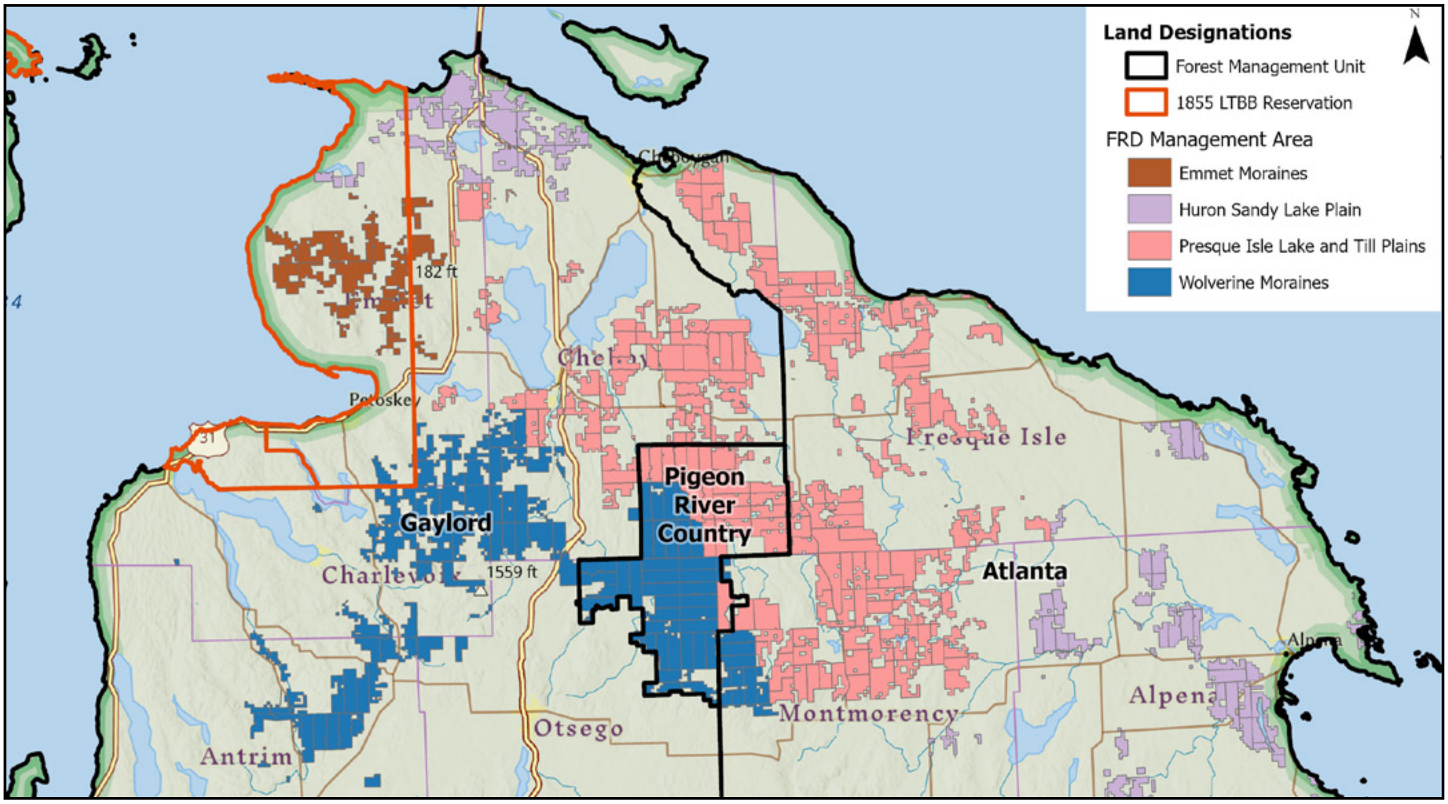

Figure 1. Land designations within northern Lower Peninsula study area, including the 1855 LTBB Reservation, FRD Management Units, and FRD management areas of state forest lands.

Acer saccharum, *A.rubrum*, *Fagus grandifolia, Tilia americana*), with intermixed stands of aspen (*Populus* spp), oak (*Quercus* spp), and planted pine (*Pinus* spp). Extensive lowland forests (dominated by *Thuja occidentalis*, *Larix laricina*, *Abies balsamea*, *Picea* spp, *Fraxinus* spp) and non-forested wetlands occur scattered along hydrographic features (e.g., lakes, streams). Elevation reaches a maximum of 440 meters (Otsego County) and much of the forested landscape is characterized by moderate to steep sloped glacial moraines.

Sampling Design

We used ArcGIS Pro (ESRI 2022) to establish a 4-km^2 hexagonal random grid over the study area to form the basis of our sampling design. This grid size was used to maximize detection of martens by approximating the minimum home range size of martens in Michigan (Gehring et al. 2019, Roloff et al. 2020) and the Great Lakes Region (Mech and Rogers 1977, Woodford et al. 2013). This grid size balances trade-offs between maximizing landscape coverage, logistical restraints, assessing fine-scale habitat associations, and detecting other medium- to large-bodied carnivores of interest (e.g., fisher [*Pekania pennanti*], coyote [*Canis latrans*], bobcat [*Lynx rufus*], and black bear [*Ursus americanus]*) (Wilton 2020). Due to land access restrictions and interest in marten occurrence on lands under active management, we focused survey areas to grid cells containing access to public lands (i.e., state forest).

In 2021 we selected an array of 75 grid cells totaling 300-km^2 (Figure 2). The survey grid was comprised of three distinct study areas, including the Pleasant View (within Emmet Moraines FRD management area), Wycamp Lake (Huron Sandy Lake Plain), and Chandler Hills (Wolverine Moraines) areas (Figure 2). In 2022 we selected an array of 67 grid cells totaling 268-km^2, comprised of three areas, including Good Hart (Emmet Moraines), Black Lake (Presque Isle Lake and Till Plains), and Jordan River (Wolverine Moraines) areas (Figure 3a, b). The center of each randomly derived grid cell or nearest public land location within a forested cover type served as an initial location for selecting camera trap placement, with one to two camera traps per grid cell.

[1] LRBOI Wildlife Division collaborative research projects with Grand Valley State University.

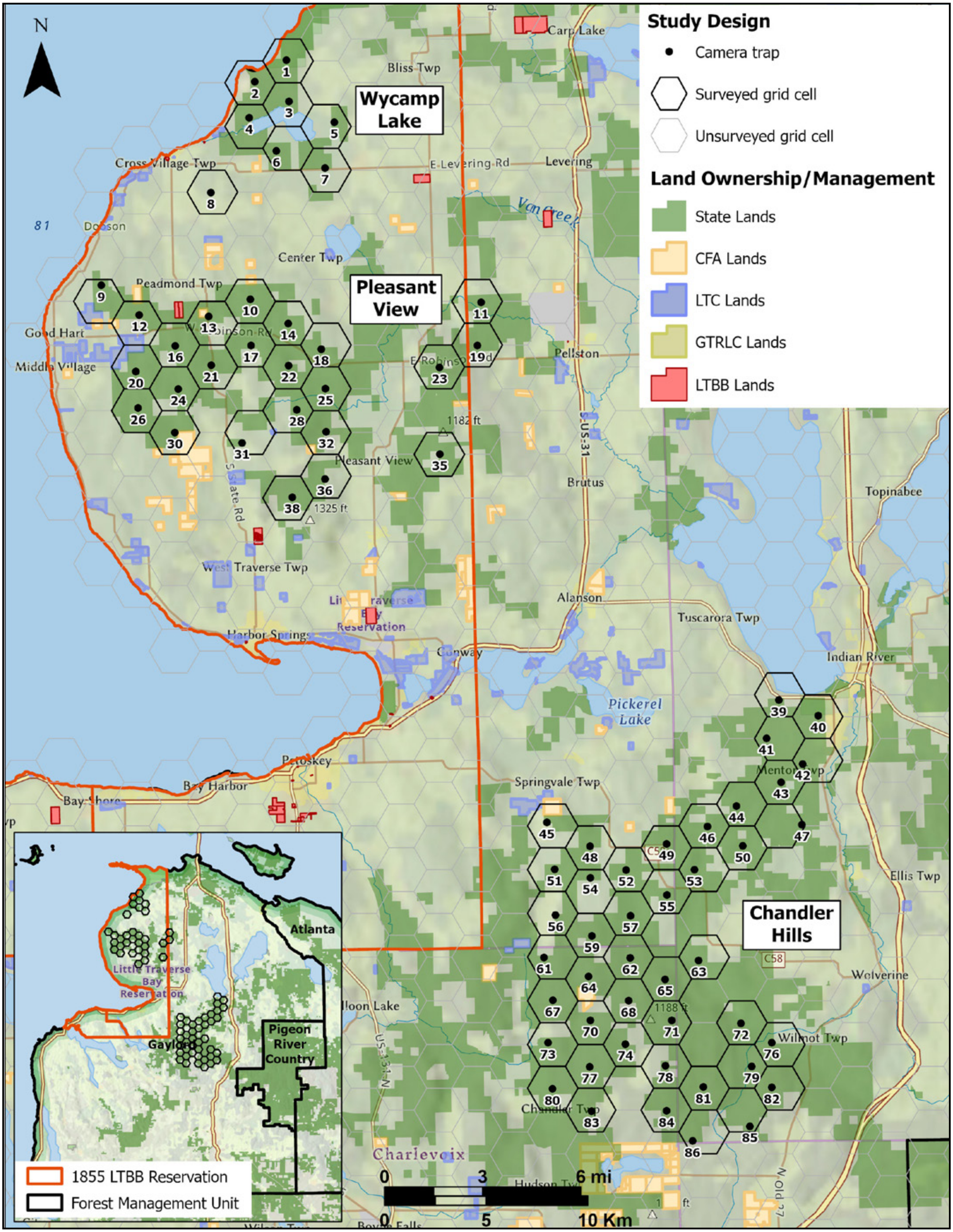

Figure 2. Camera trap study design during the 2021 survey effort.

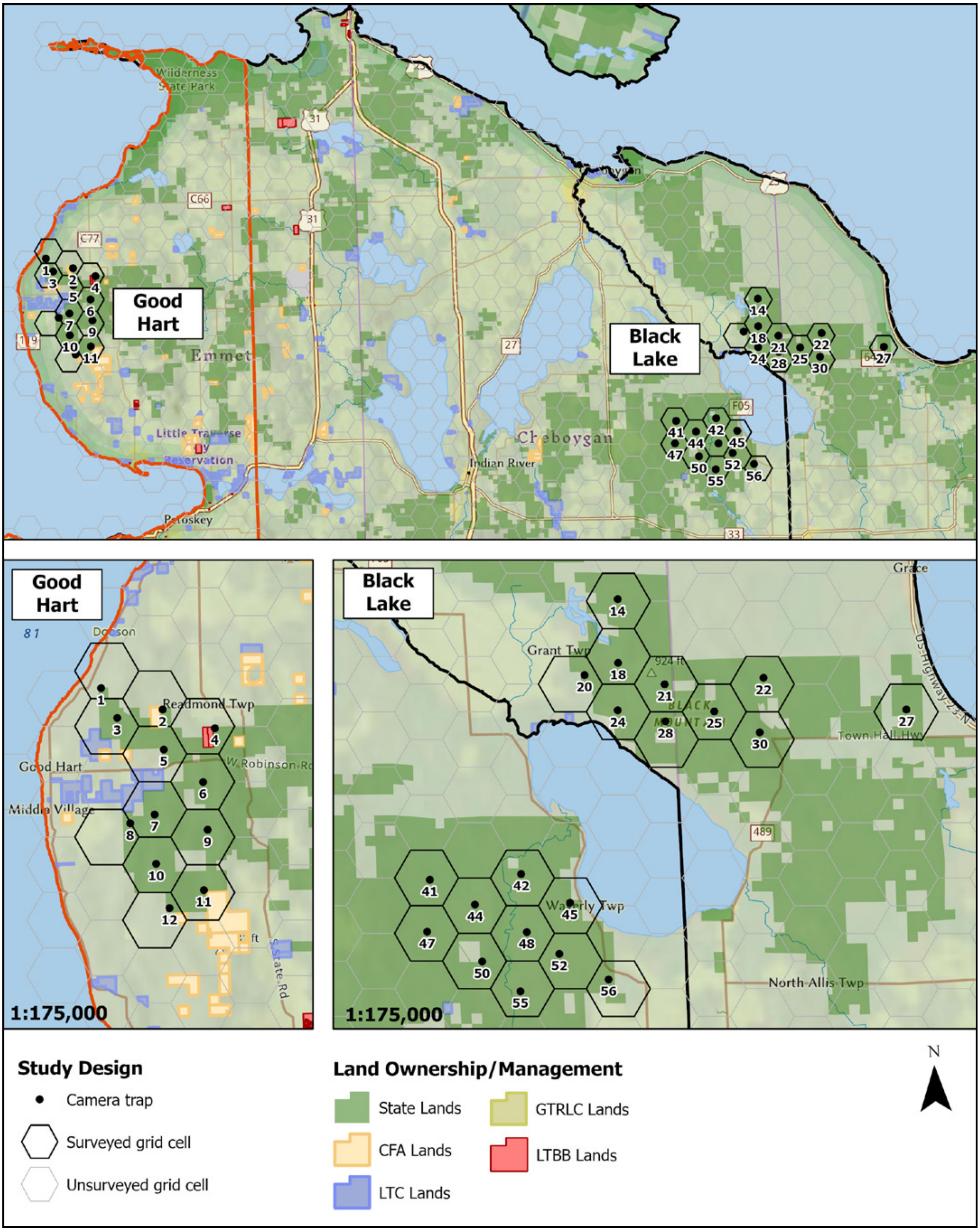

Figure 3a. Camera trap study design during the 2022 survey effort, including the Good Hart and Black Lake study areas.

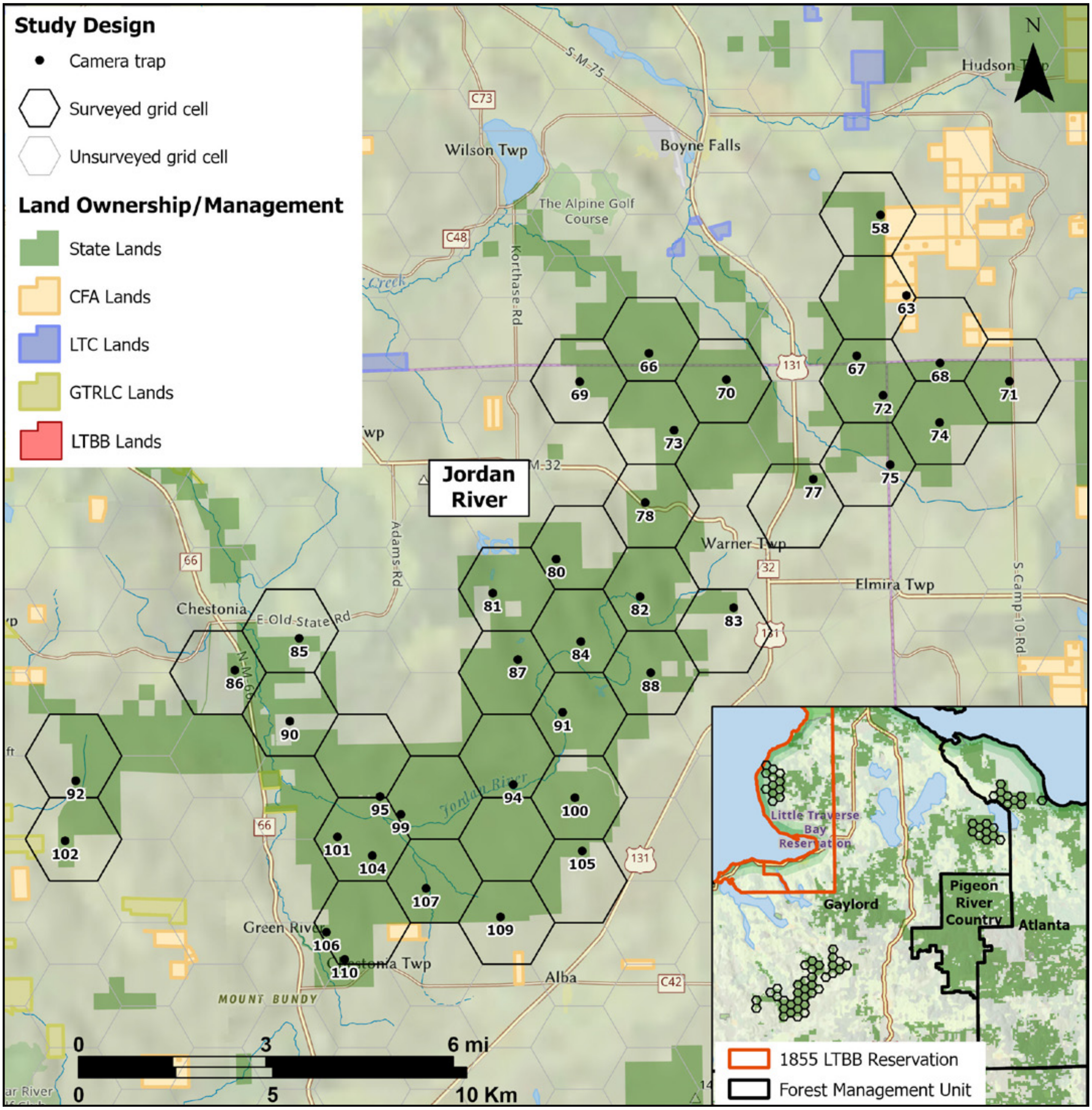

Figure 3b. Camera trap study design during the 2022 survey effort, including the Jordan River study area site within the Wolverine Moraines FRD management area.

Field Sampling

We deployed 75 passive infrared camera traps (Browning Spec-Ops Advantage, model BTC-8A, Birmingham, Alabama, USA) in 2021 and 70 camera traps in 2022, each programmed to take 2 photos per trigger (Rapidfire mode) with a 1-second delay between consecutive triggers. We used a predator trapping lure (Gusto and Skunk Junk; Minnesota Trapline Products) placed in a biodegradable cup and suspended from a branch about 2 meters above ground in front of each camera to increase the likelihood of attracting a marten or fisher within a camera's detection zone. We deployed cameras in January and retrieved all cameras in May during each 2021 and 2022 survey period ($\bar{x}$ = 105, range = 85–126 days). We revisited camera sites 1–3 times between deployment and retrieval to reapply lure, replace memory cards and batteries, and maintain camera operation (Appendix I).

Within a 100-meter radius of the initial random location, we searched until a location having a suitable field of view to allow marten and fisher to be photographed was found. Camera site selection was further refined by aiming the camera's detection zone towards available fine-scale natural features that may facilitate marten and fisher detection, with an emphasis on large coarse woody debris. We avoided placing cameras on human-use roads and trails to minimize theft or vandalism.

Cameras were mounted about 0.5–1.0 meters above ground to a tree and about 3–5 meters from the target detection zone (e.g., CWD feature). We aimed cameras facing North, if possible, to minimize false triggers caused by exposure to the sun's rays. If applicable, we mounted cameras at about a 45-degree angle to linear log features to maximize detection of traveling animals. We trimmed vegetation obstructing the camera's detection zone and vegetation that may falsely trigger the camera.

We ranked the abundance of CWD at a camera trap site using 4 general categories (0, 1–10, 11–20, >20), representing the number of down trees and tree root masses visible within a 360° scan while standing at a site. We measured the maximum distance a camera was able to detect a passing animal (Detection Distance) by setting the camera to Motion Test mode and walking back-and-forth in front of the camera at increasing distance until the camera was no longer triggered (Appendix I, Appendix II). This metric serves as an index of horizontal vegetation density or topography that may obstruct a camera's view and detection probability. We described the general forest cover type surrounding a camera site to validate against GIS-based land cover layers used in occupancy analyses.

We triggered cameras upon arrival and before leaving each site by holding an informational whiteboard with date, time, camera ID, visit #, and observer initials. This provided a confirmation of a camera's operational status and a basic digital backup of a site's datasheet. (Appendix II).

Image Processing

We downloaded images from memory cards after each camera check and organized images into folders distinguished by camera site and subfolders by camera visit number (e.g., "visit1"). This folder structure was designed to facilitate data extraction using the package *camtrapR* (Niedballa et al. 2016) in program R (www.r-project.org), which reads images according to this specified structure and renames each image file with its respective site ID, visit number, date taken, time taken, and image sequence number (e.g., 10__visit1__2021-01-27__23-38-35(1).JPG). We used the RECONN.ai (Michigan Aerospace Corporation, Ypsilanti, MI, USA) machine learning software to classify species and manage image organization.

Occupancy Analysis

We defined a positive marten detection at a camera site as at least one image of marten collected per day. For each camera site, we used *camtrapR* to generate a daily detection history, where a "1" indicates a positive marten detection and a "0" represents a non-detection event for a given day. For example, a detection history of “01011” illustrates a detection history where a marten was not detected on the first day, detected on the second day, not detected on the third day, and detected on the last 2 days.

Due to the sparse positive detections typical of carnivore surveys and associated limitations of zero-inflated datasets, we collapsed raw daily occasions into 24, 5-day occasions for both 2021 and 2022 datasets. This period was the shortest occasion length that permitted convergence of occupancy models.

We used single-species, single-season occupancy modeling (MacKenzie et al. 2002) in a likelihood-based model selection framework (Akaike Information Criterion (AIC; Arnold 2010) to test and rank the relative support among hypotheses about factors affecting marten occupancy probability from our detection-nondetection camera trap data.

We used a two-step approach to first determine the most parsimonious model explaining detection probability, and then included these detection covariates in all combinations of our occupancy models (Erb et al. 2012). All numerical covariates were first standardized by subtracting the mean and dividing by the standard deviation of each covariate. During the first step, we included all possible occupancy covariates as a constant while investigating each combination of detection covariates. In the second step, the resulting most supported detection model was held constant while all combinations of occupancy covariates were investigated. We then used the final most supported model describing detection probability and occupancy probability to predict and describe marten occupancy throughout the study area.

For the first step, we modeled the abundance of CWD that occurred at a site (4 categories), and by survey period (Time). The covariate Time was investigated by dividing the total survey length into 6 equal length intervals to test for changes in marten detection over each camera’s deployment period. We hypothesized that marten detection probability would increase with increasing abundance of CWD at a camera site, and that detection probability would decrease over the study duration. Low overall sample size precluded assessment of more complex models.

For the second step, we generated land cover covariates to investigate their influence (either positive or negative) on marten occupancy probability. For each covariate, we used ArcGIS Pro to extract values at a 4-km^2 spatial scale as this represents the minimum expected home range size of marten in this region (Gehring et al. 2019, Roloff et al. 2020). We used LANDFIRE’s Existing Vegetation Type (EVT) classification layer (30-m^2 resolution) to extract all land cover covariates (Rollins 2009) and reclassified 25 focal EVT group names into 5 ecological classes of interest, including ‘upland deciduous forest’ (UDF), ‘upland conifer forest’ (UCF), ‘mixed forest’ (MF), ‘lowland forest’ (LF), managed tree plantation (MTP), and all other classes (Wilton 2021). We calculated the proportion of LF, UDF, UCF, MF, MTP, and total forest cover (ForCov) within a 4-km^2 circular buffer surrounding the camera site. We used this buffer instead of the hexagonal grid area to account for camera sites that were unable to be placed at its geographic center. The proportion of forest cover was derived from the summation of all forested land cover classes within each buffer. We included these cover types because they are either the most dominant natural land cover classes in the study area or may be important drivers of marten resource selection (Roloff et al. 2020). The proportion of total forest cover within a buffer may positively influence marten occupancy because of their dependence on forested cover types (Hargis et al. 1999). Specifically, we hypothesized that marten occupancy probability would increase with increasing proportion of UDF, UCF, MF, and ForCov but decrease with increasing proportion of LF and MTP.

We considered models to have competing support if they were within 2.00 ΔAIC of the most supported model and assessed proportional support for each model using AIC weights (w_i; Burnham and Anderson 1998). We examined the significance of each covariate in competing models by determining if the 95% confidence interval (CI) of the beta coefficients overlapped zero (significance = non-overlapping CI). All analyses were performed using the package *unmarked* (Fiske and Chandler 2011) in RStudio (v. 2023.03.0; R Core Team 2023).

Michigan Forest Inventory (MiFI) Assessment

We used ArcGIS Pro to generate an intersection of all clearcut and selective cut treatment methods currently available in the MiFI database (2011–2021) with each 4-km^2 circular buffer around camera traps (MDNR 2009). We then summarized the treatment methods within each FRD management area (Figure 1) in relation to their density, treatment cover type, and presence of marten.

Results

Field Sampling

2021

We deployed 75 camera traps for a total survey effort of 7,718 active trap nights. Average camera deployment period was 103 days (range = 90–114 days). One camera was not operational for 31 days from its deployment date to its first check date (31 days), one camera was not operational for 11 days due to a full memory card from false triggers, and one camera was not operational for 34 days due to theft (Figure 4a).

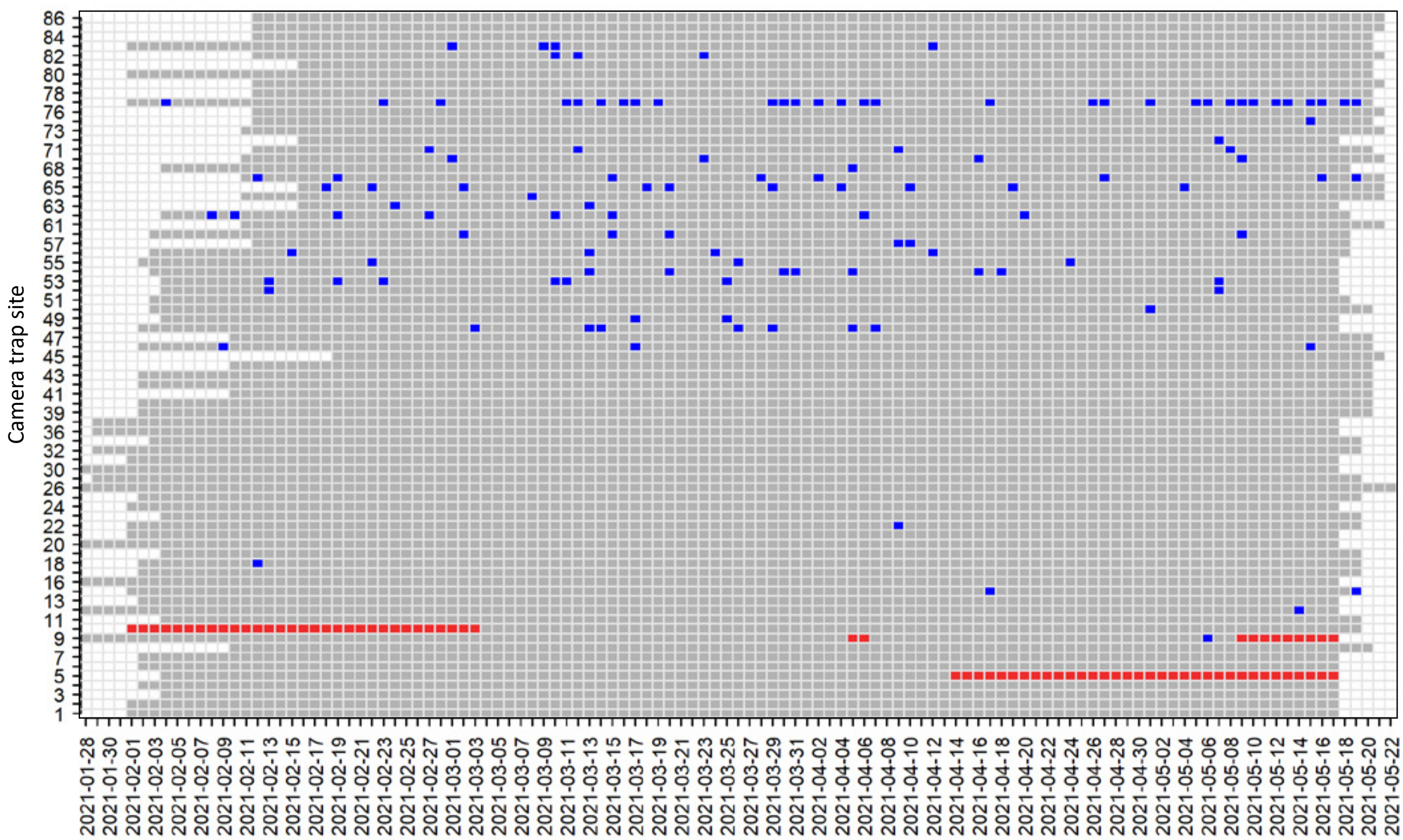

Figure 4a. Camera trap site operation matrix displaying days when cameras were deployed and operative (gray squares), deployed but inoperative (red squares), not deployed (white squares), and days when a marten was detected (blue squares) at a camera trap site during 28 January– 22 May 2021.

2022

We deployed 70 camera traps for a total survey effort of 7,446 active trap nights. Average camera deployment period was 106 days (range = 85–126 days). One camera was not operational for 16 days due to dead batteries, one camera was not operational for 18 days due to a full memory card from false triggers, and one camera was not operational for 9 days due to vandalism (Figure 4b).

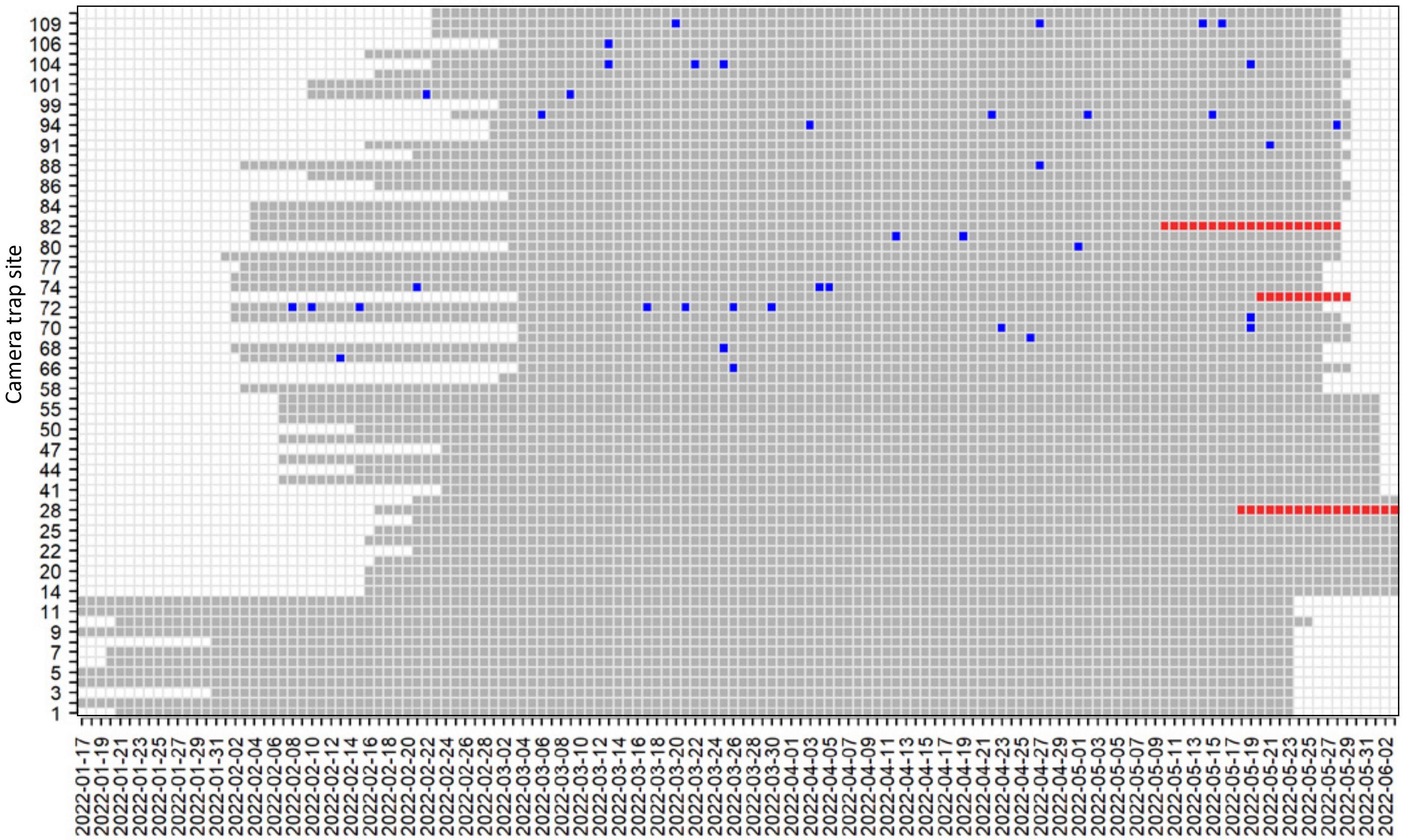

Figure 4b. Camera trap site operation matrix displaying days when cameras were deployed and operative (gray squares), deployed but inoperative (red squares), not deployed (white squares), and days when a marten was detected (blue squares) at a camera trap site during 17 January– 02 June 2022.

Image Processing

2021

Camera traps collected 287,418 images, including animal detections, non-animal detections, and false triggers. Marten triggered cameras 419 times at 29 unique camera sites located within the Chandler Hills (Wolverine Moraines) and Pleasant View (Emmet Moraines) study areas (Figure 5). We detected marten at 39% (i.e., naïve occupancy) of total survey sites. At sites having marten detections, the number of daily detections averaged 4.3 (SD = 5.7, range = 1 – 31), with 126 total daily detections across sites (Figure 6).

2022

Camera traps collected 201,678 images, including animal detections, non-animal detections, and false triggers. Marten triggered cameras 138 times at 18 unique camera sites located within the Jordan River (Wolverine Moraines) study area (Figure 7). We detected marten at 26% (i.e., naïve occupancy) of total survey sites. At sites having marten detections, the number of daily detections averaged 2.2 (SD = 1.7, range = 1 – 7), with 39 total daily detections across sites (Figure 6).

Occupancy Analysis

2021

The composition of land cover covariates used to evaluate occupancy probability was similar among most survey sites (Figure 5). Most site areas (i.e., 4-km^2 buffer) were dominated (≥ 50% of cover class) by upland deciduous forest (n = 55 sites), though two were dominated by upland conifer forest (Chandler Hills study area) and one by lowland forest (Wycamp Lake study area). Overall, mean percent cover type among site areas was 65.4% for upland deciduous forest, 9.4% for upland conifer forest, 6.3% for lowland

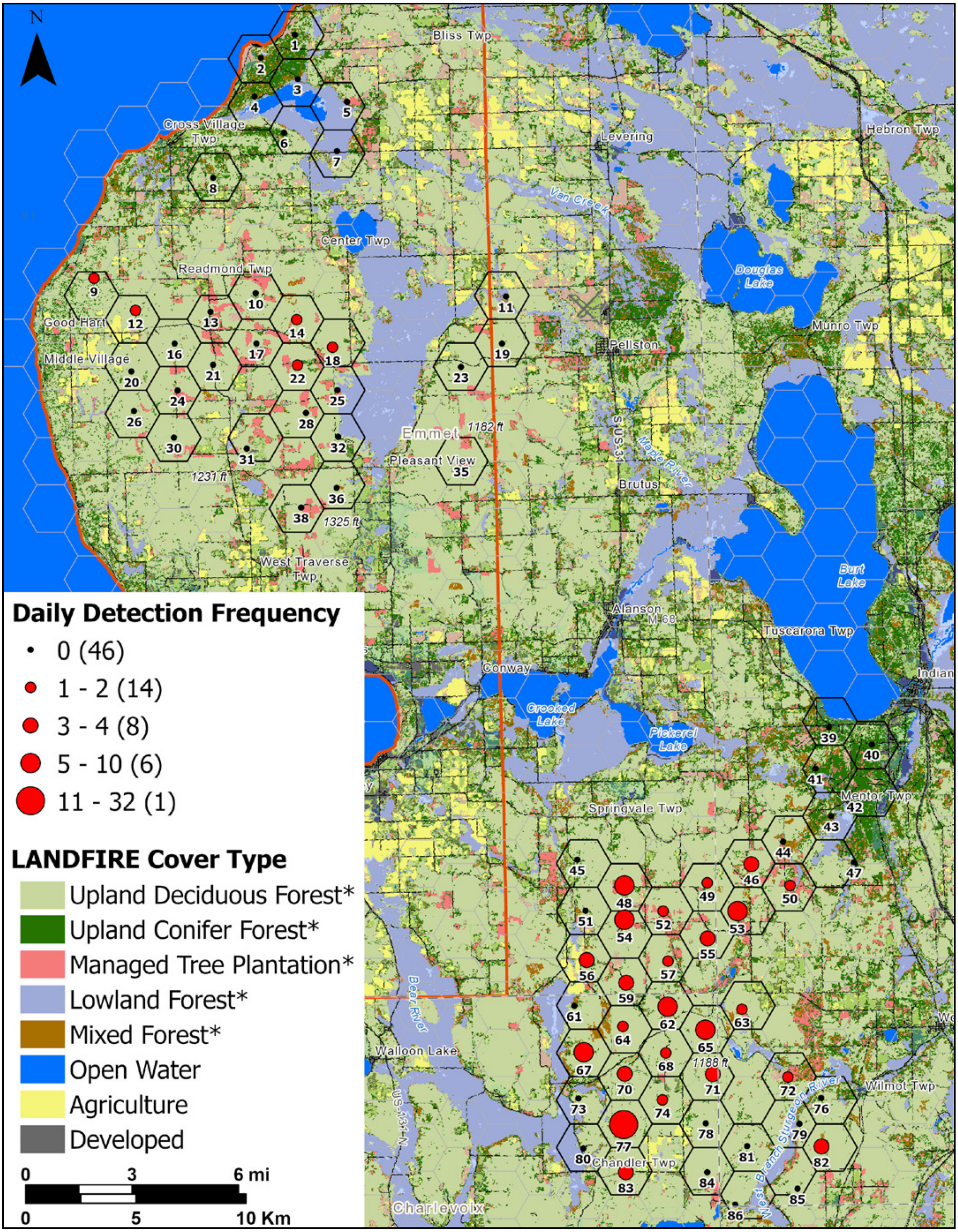

Figure 5. Marten daily detection frequency during 2021 survey effort in relation to LANDFIRE land cover covariates. Cover types with asterisks were included as model covariates.

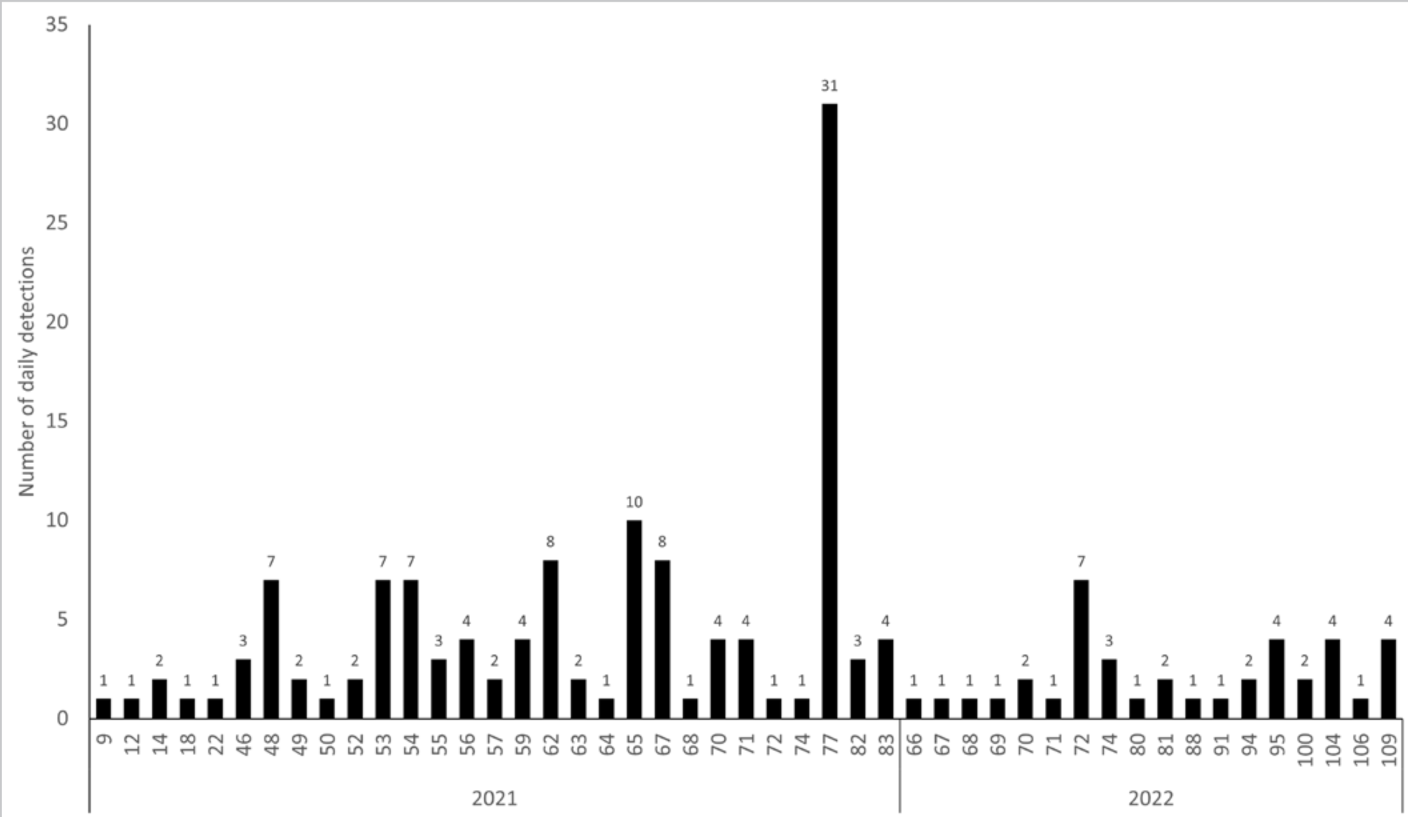

Figure 6. Number of daily marten detections at camera trap sites having at least one marten detection during 2021 and 2022 survey efforts.

forest, 3.1% for mixed forest, and 4.8% for managed tree plantation. Total forest cover among site areas averaged 92.2% (Table 1).

The top-supported occupancy model included the proportion of lowland forest, mixed forest, and upland conifer forest occurring within each camera site's 4-km^2 buffer area (Appendix III). This model suggested lesser marten occupancy probability in areas having proportionally greater lowland forest cover (β = -2.97, SE = 1.58, p-value = 0.06) or upland conifer forest (β = -1.44, SE = 0.80, p-value = 0.07), and greater marten occupancy probability in areas having proportionally greater mixed forest (β = 0.82, SE = 0.56, p-value = 0.15). All covariates were included in at least one of the 10 competing models, which comprised 53% of the cumulative model weight (Appendix III). These included covariates having a positive (UDF, MF) and negative (UCF, LF, MTP) relationship with marten occupancy probability (Figure 8). Only the proportion of upland deciduous forest was considered a significant (α = 0.05) and positive predictor of marten occupancy probability (β = 1.20, SE = 0.59, p-value = 0.04).

Table 1. Mean proportion of LANDFIRE land cover covariates occurring within each survey grid cell.

Site Covariate	Mean	SD	Min	Max
2021				
Upl. deciduous forest	65.4	25.4	5.3	93.2
Tree plantation	4.8	5.5	0.0	22.9
Lowland forest	6.3	12.0	0.0	53.2
Upl. conifer forest	9.4	12.6	0.7	63.8
Mixed forest	3.1	3.5	0.0	14.4
Forest cover	92.2	8.2	59.8	99.9
2022				
Upl. deciduous forest	57.9	30.0	0.5	94.8
Tree plantation	2.8	3.5	0.0	14.0
Lowland forest	10.1	13.3	0.0	60.7
Upl. conifer forest	12.9	15.9	1.0	59.2
Mixed forest	4.9	6.2	0.0	24.6
Forest cover	92.1	7.4	60.5	99.8

Overall marten occupancy probability derived from the top-supported model was 0.19 (95% CI = 0.05–0.48). The density of coarse woody debris (CWD) at camera sites was a significant positive predictor of marten detection probability (β = 0.18, SE = 0.15, p-value = 0.02).

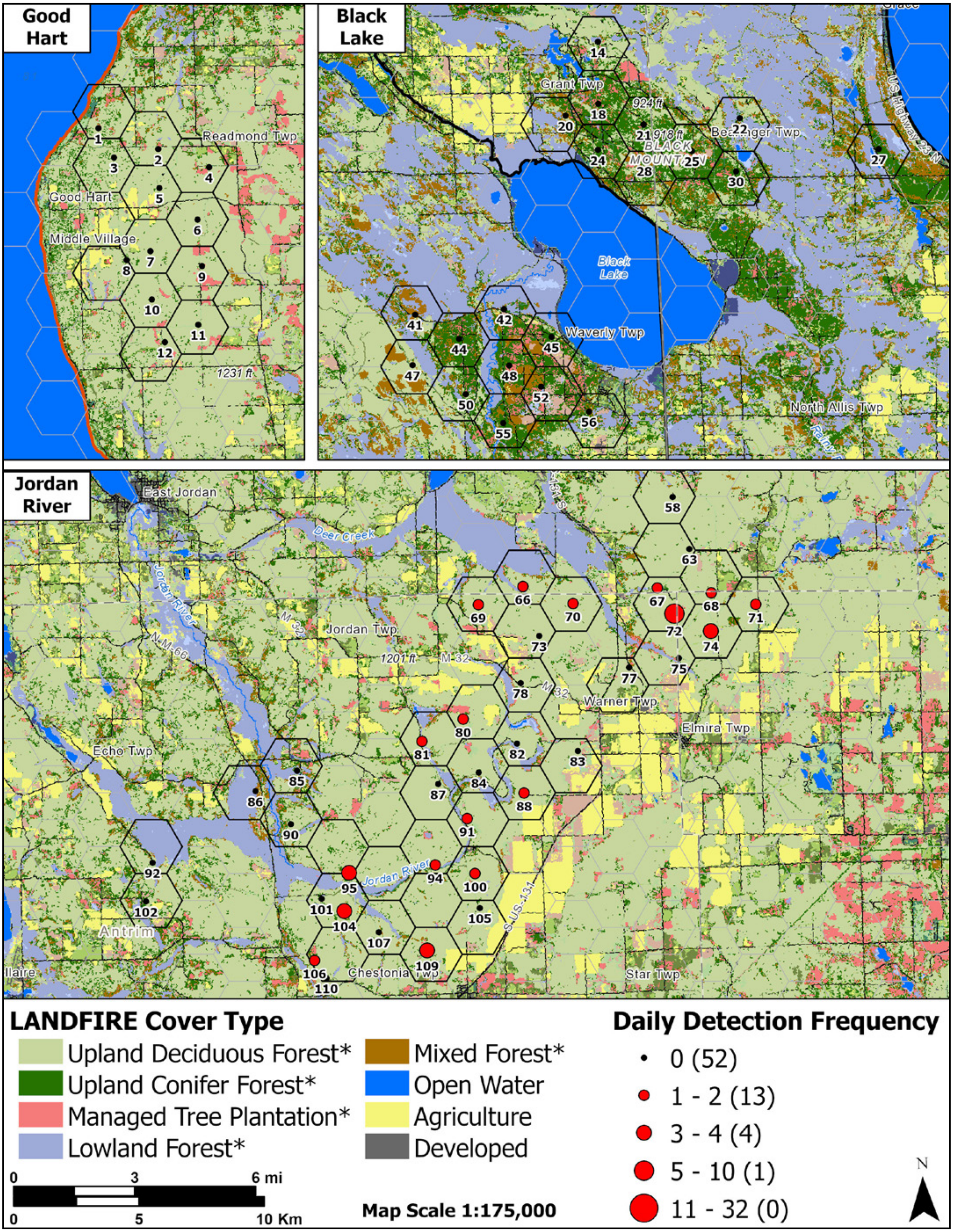

Figure 7. Marten daily detection frequency during 2022 survey effort in relation to LANDFIRE land cover covariates. Cover types with asterisks were included as model covariates.

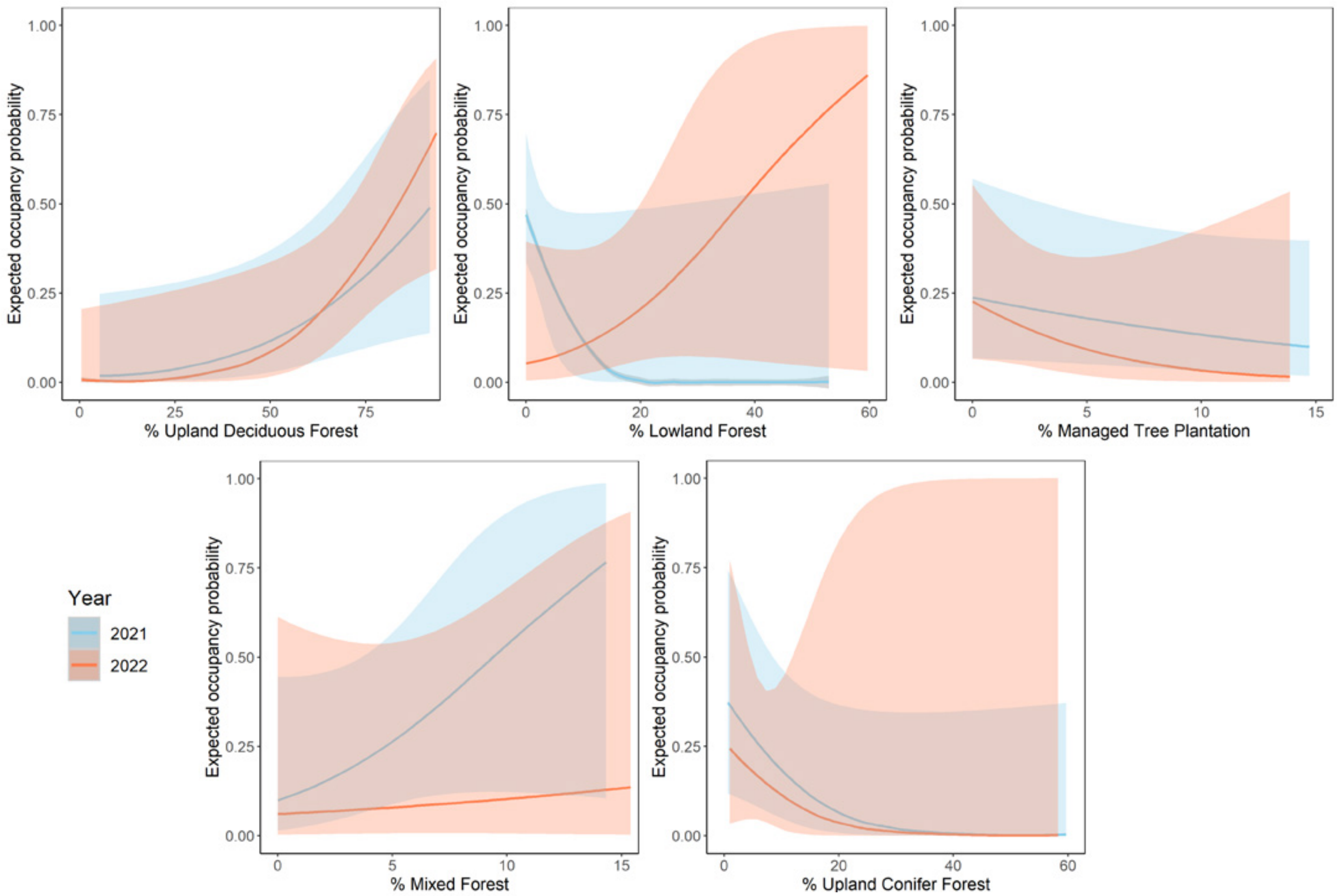

Figure 8. Change in predicted marten occupancy probability as a function of LANDFIRE site covariates, including the percent of upland deciduous forest, lowland forest, managed tree plantation, mixed forest, and upland conifer forest within 4-km^2 circular buffers. Shaded bands represent 95% confidence intervals.

2022

The composition of land cover covariates used to evaluate occupancy probability was similar among most survey sites within the Good Hart and Jordan River study areas but differed within the Black Lake area (Figure 7). Black Lake camera traps were predominately surrounded by conifer cover types compared to deciduous cover types of the other study areas. Most site areas (i.e., 4-km^2 buffer) were dominated (≥ 50% of cover class) by upland deciduous forest (n = 46 sites), though three sites were dominated by upland conifer forest (Black Lake area) and one site by lowland forest (Jordan River area). Overall, mean percent cover type among site areas was 57.9% for upland deciduous forest, 12.9% for upland conifer forest, 10.1% for lowland forest, 4.9 for mixed forest, and 2.8% for managed tree plantation. Total forest cover among site areas averaged 92.1% (Table 1).

The top-supported occupancy model included the proportion of managed tree plantation and upland deciduous forest occurring within each camera site's 4-km^2 buffer area (Appendix III). This model suggested lesser marten occupancy probability in areas having proportionally greater managed tree plantation cover (β = -0.74, SE = 0.61, p-value = 0.22) and greater marten occupancy probability in areas having proportionally greater upland deciduous forest (β = 2.18, SE = 0.95, p-value = 0.02). All covariates were included in at least one of the 12 competing models, which comprised 61% of the cumulative model weight (Appendix III). These included covariates having a positive (UDF, MF, LF) and negative (UCF, MTP) relationship with marten occupancy probability (Figure 8). Only the proportion of upland deciduous forest was considered a significant (α = 0.05) and positive predictor of marten occupancy probability.

Overall marten occupancy probability derived from the top-supported model was 0.14 (95% CI = 0.04–0.38). The density of coarse woody debris (CWD) at camera sites was a positive predictor of marten detection probability but not significant ($\beta = 0.32$, SE = 0.35, p-value = 0.35).

Michigan Forest Inventory (MiFI) Assessment

The Wolverine Moraines FRD management area contained the most camera trap sites with marten detections during both 2021 and 2022 surveys, including 65% (n = 24) and 47% (n = 18) of camera traps, respectively. The 24 camera traps with marten detections in the Chandler Hills area of the Wolverine Moraines encompassed 12 of 20 (60%) surveyed state forest compartments, and the 18 sites with marten detections in the Jordan River area encompassed 11 of 13 (85%) compartments. Moreover, the Wolverine Moraines, particularly the Chandler Hills study area, had the greatest frequency of daily marten detections among 2021 and 2022 study areas (Figure 5, Figure 7). The Emmet Moraines area in 2021 was the only other region to detect martens, with 21% (n = 5) of sites documenting marten (Figure 5).

Similarly, the majority (85%) of marten detections during 2021 and 2022 surveys occurred in northern hardwood MiFI cover types, which dominated much of the study area (Figures 9, 10, 11). Other hardwood types (mixed upland deciduous, red oak, aspen) comprised 8% of marten detections, with planted red pine making up the remaining 7% of camera traps that detected marten (Appendix IV). These associations largely reflect the cover types within which cameras were deployed, where 62% were set in northern hardwoods, 17% in other hardwood types, 9% in planted red pine, and 12% in various other forested cover types.

Within the Emmet and Wolverine Moraines, martens were detected both at camera traps having clearcut and selectively cut treatments within their 4-km^2 site buffers. Specifically, camera traps in the Emmet Moraines that detected martens had a four-fold greater proportion of selectively cut lands within their buffers than camera traps without a marten detection but were similar in their proportions of clearcut lands. However, camera traps in the Wolverine Moraines that detected martens had lower proportions of both clearcut and selectively cut lands than camera traps without a marten detection (Figure 12). Three camera traps occurred directly within stands that received a clearcut treatment between 2007 and 2022, with marten detections occurring in one of these stands (clearcut in 2007). Fifteen camera traps occurred within stands that received a selective cut treatment between 2007 and 2022, with marten detections occurring in nine of these stands (Figures 9, 10, 11).

All FRD management areas, except the Huron Sandy Lake Plain, surveyed during 2021 and 2022 had a similar proportion of their survey footprint (i.e., sum of 4-km^2 site buffers) impacted by harvest treatments (range 8.2–9.2%), but differed in the relative proportions of clearcut and selective cut methods (Figure 13). Both the Emmet Moraines and Wolverine Moraines have experienced a greater proportion of selective cuts than clearcuts, while the Presque Isle Lake and Till Plains have experienced the opposite. Within the Emmet Moraines, northern hardwood clearcut and selective cut treatments covered about the same proportion of our survey footprint (26% and 28%, respectively), whereas the Wolverine Moraines show a two-fold increase in the proportion of selectively cut to clearcut northern hardwoods (75% and 33%, respectively) and represents the most prevalently harvested cover type in this area. Only in the Emmet Moraines and Presque Isle Lake and Till Plains do treatments of aspen and planted pine occur in greater proportions than northern hardwood treatments (Appendix V).

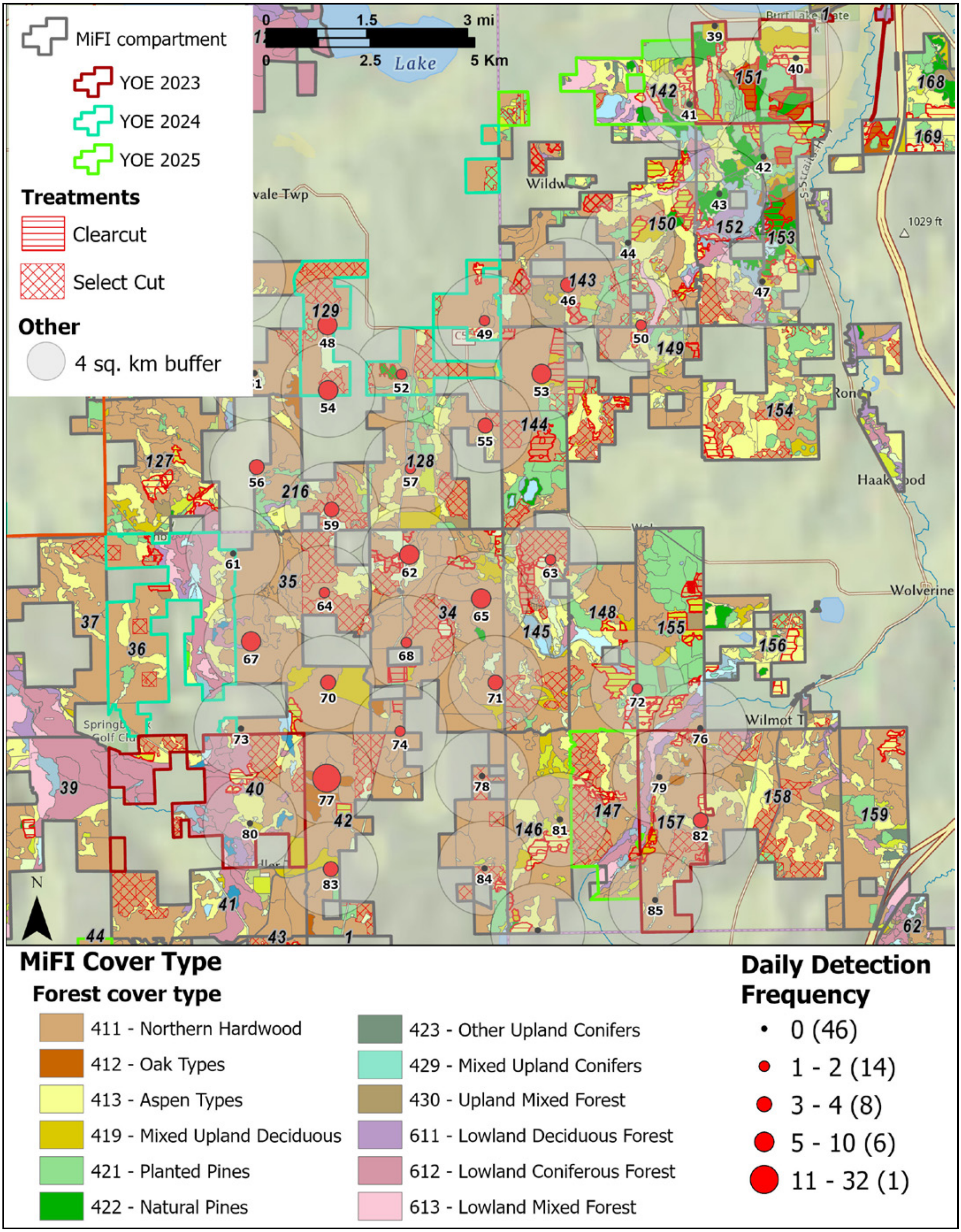

Figure 9. Marten daily detections during 2021 survey in relation to timber harvest treatments. Location: Chandler Hills study area of the Wolverine Moraines FRD management area. YOE = Year of Entry.

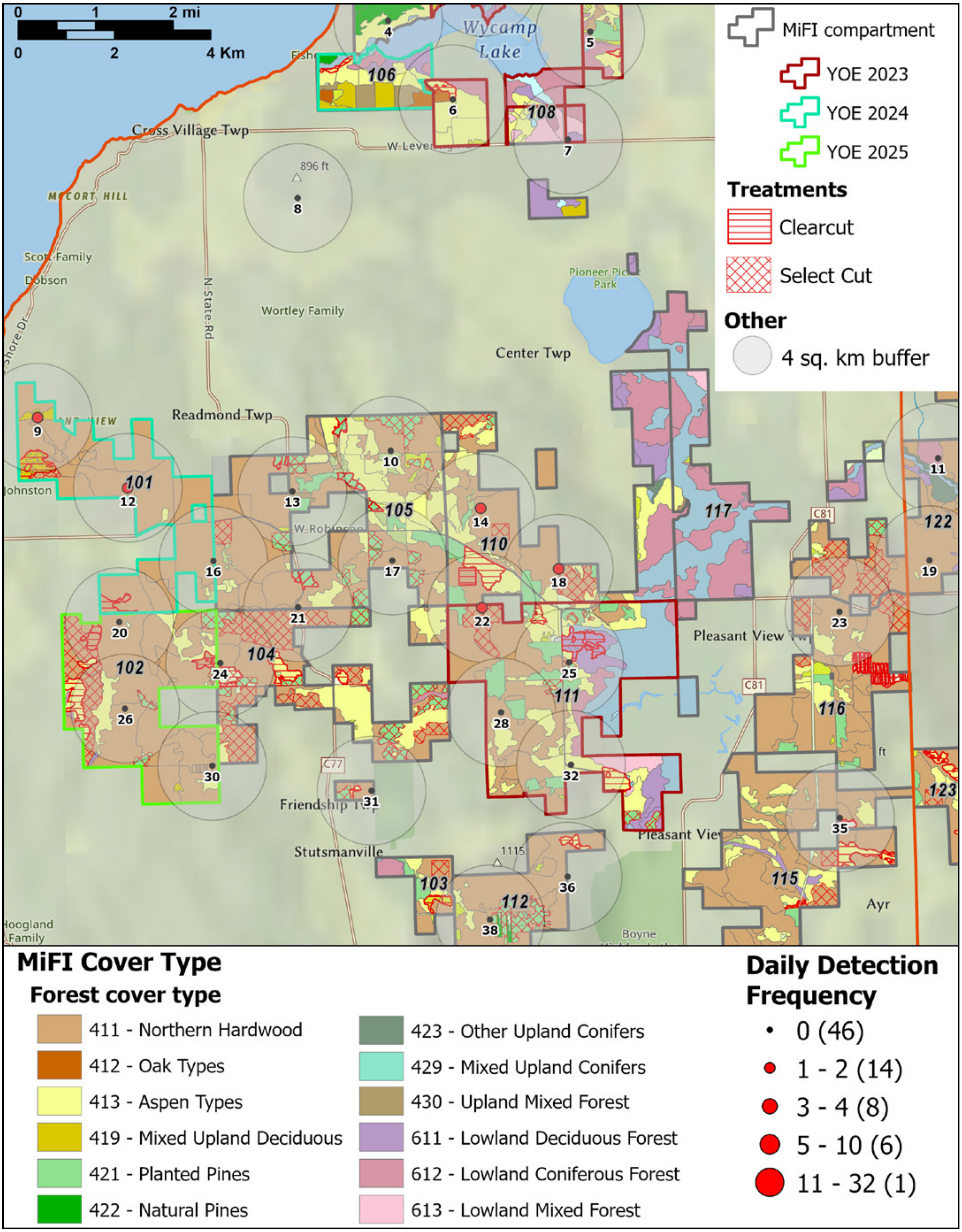

Figure 10. Marten daily detections during 2022 survey in relation to timber harvest treatments. Location: Pleasant View study area of the Emmet Moraines FRD management area. YOE = Year of Entry.

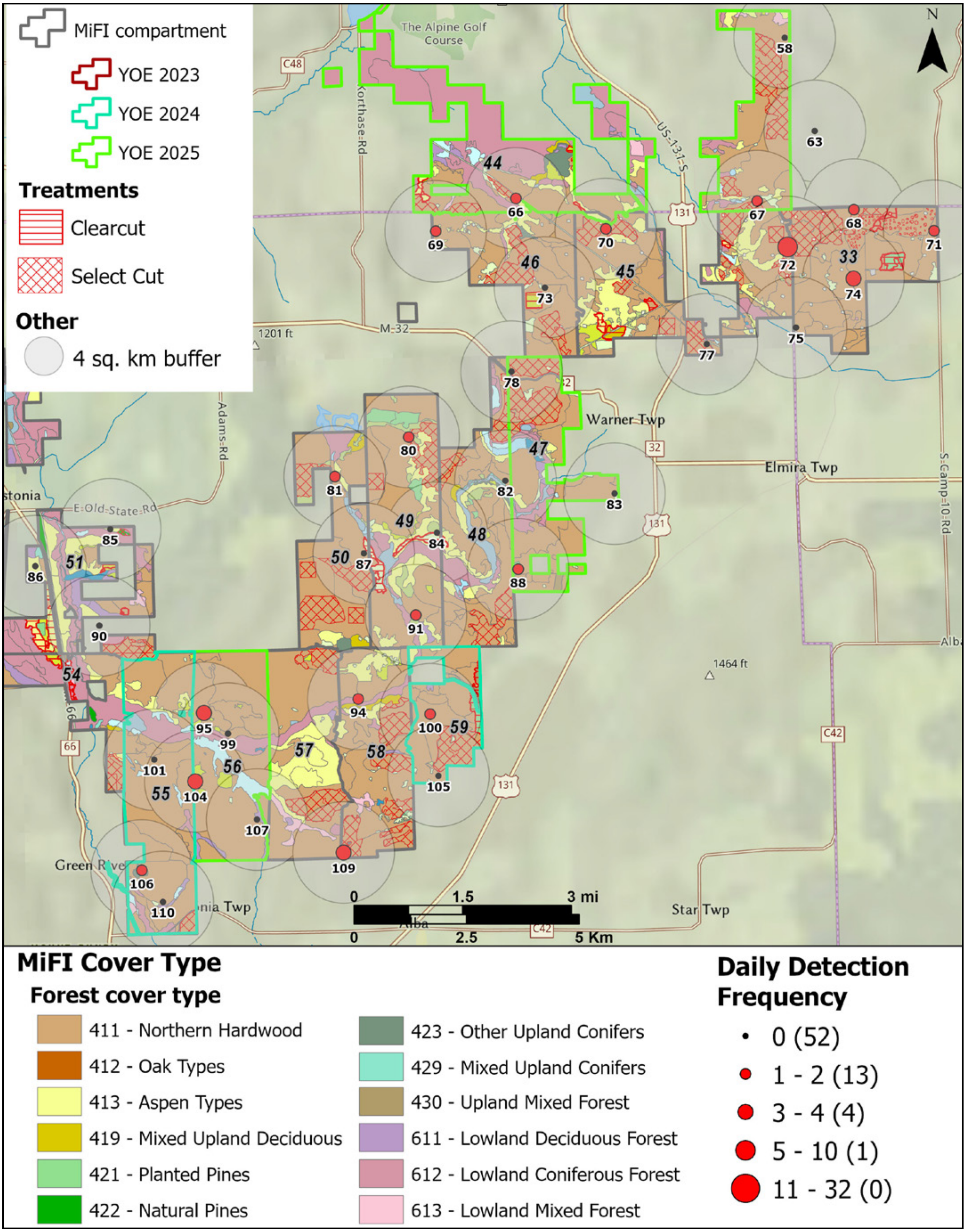

Figure 11. Marten daily detections during 2022 survey in relation to timber harvest treatments. Location: Jordan River study area of the Wolverine Moraines FRD management area. YOE = Year of Entry.

Discussion

Since 2020, annual camera trap surveys have revealed critical information on the distribution and conservation priorities for marten in the NLP. Initial efforts in 2020 formed a foundation for understanding where, and under what ecological conditions, marten occur or are most likely to occur in our study area (Wilton 2021). Surveys in 2021 and 2022 continued to build upon this foundation by expanding our knowledge of the spatial distribution of marten occurrences on state forest lands and enhancing our understanding of fine-scale distribution and habitat associations in previously surveyed regions. For example, much of the Emmet Moraines management area has been surveyed for marten, fisher, or black bear since 2019 (Wilton 2020, 2021) and 2021–2022 surveys continued to demonstrate a low but persistent occurrence of marten. Additionally, the 2021 survey in the Chandler Hills study area of the Wolverine Moraines greatly expanded our understanding of marten distribution in this area. Since 2020, we detected marten at 42 unique camera trap sites across 14 of 22 surveyed state forest compartments in the Chandler Hills area, making it a regionally important area of marten habitat to the NLP.

In 2022, we continued to expand marten survey efforts to new areas, including the Jordan River area of the Wolverine Moraines and the Black Lake area of the Presque Isle Lake and Till Plains. Though the Black Lake study area failed to detect any marten at the 20 camera traps deployed here, the Jordan River study area appears to harbor a widespread but patchy distribution of marten. Our initial survey of the Jordan River area suggests marten are concentrated in the northern and southern portions of the compartment complex, but continued monitoring is needed to better understand spatial patterns of occupancy. Preliminary data from scat detection dog surveys in the Jordan River area further support this region as important marten habitat (LTBB, *unpublished data*).

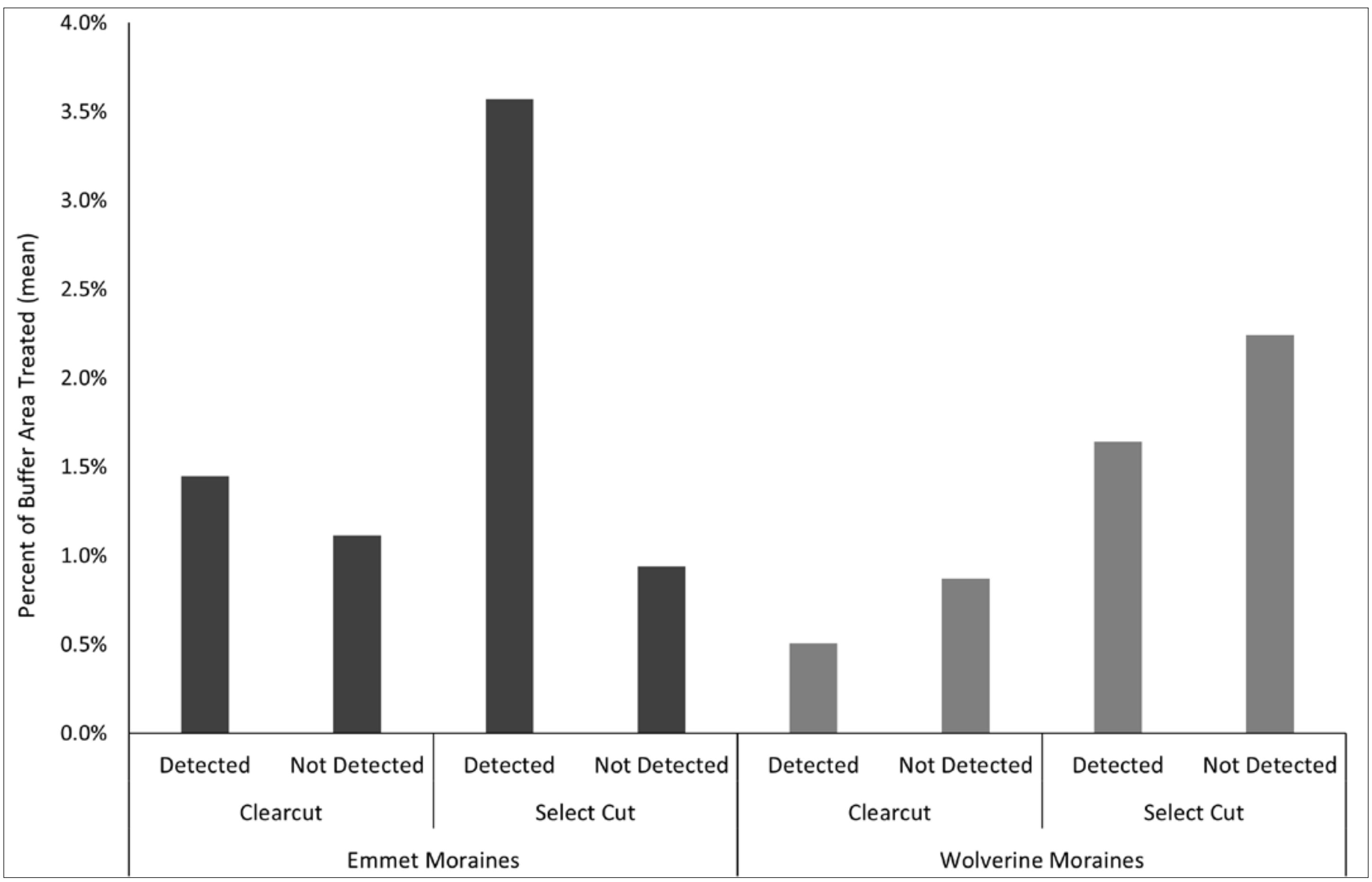

Figure 12. Percent of 4-km^2 buffers around cameras where marten were detected or not detected (2021-2022) under different treatment methods between 2011 and 2021 within the Emmet and Wolverine Moraines.

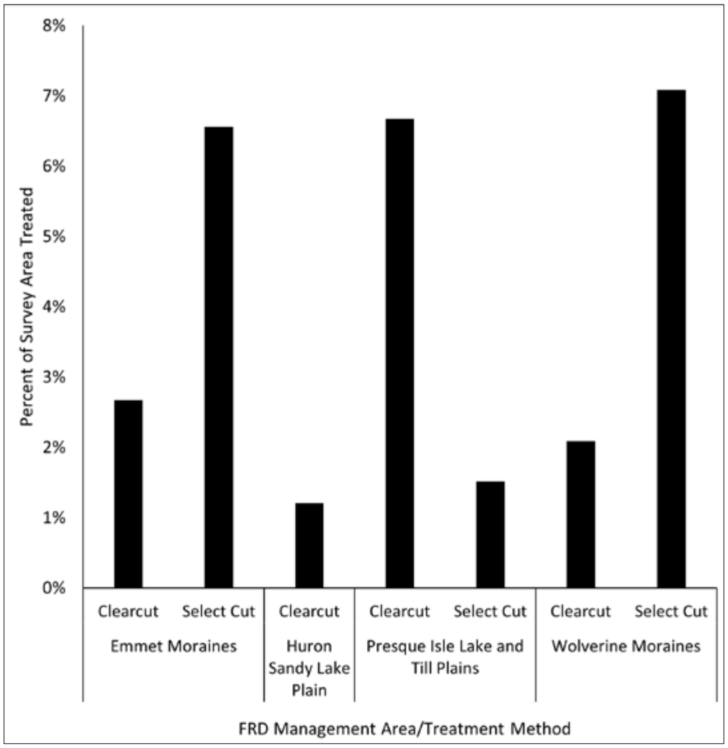

Figure 13. Percent of total survey area (sum of 4-km^2 buffers) under clearcut and select cut methods within each FRD management area surveyed during 2021-22.

Single-season occupancy analyses of 2021 and 2022 surveys largely support inferences of habitat associations found in the 2020 survey (Wilton 2021). The proportion of upland deciduous forest (i.e., northern hardwood) surrounding camera trap sites continued to be the most significant positive predictor of marten occupancy throughout the study area. This relationship is expected given its dominance across the western NLP and corroborates marten resource use at similar scales found by other studies where marten occupy upland deciduous dominated landscapes (McFadden 2007, Gehring, et al. 2019, Roloff et al. 2020). In the Chandler Hills and Jordan River study areas of the Wolverine Moraines, where northern hardwood cover types comprise about 60% of state forest compartments, the region's ecological capacity to support the observed distribution of marten is likely dependent in part on their ability to meet minimum life history needs within northern hardwood communities.

Similarly, managed tree plantations, predominately planted red pine, showed a consistent negative relationship with marten occupancy probability among survey years and was included in the 2022 top-supported model. However, parameter estimates were not statistically significant in either survey year, which may be explained by the low and patchy prevalence of planted pines on the landscape (i.e., sample bias) or because these relatively small areas do not confer a strong attraction or avoidance mechanism on marten resource use at the home range scale.

In contrast, lowland forest was inconsistent among years in its predicted direction and magnitude of effect on marten occupancy probability and was not statistically significant in any survey year. In 2020, the few sites that included lowland forest in the surrounding area detected marten within adjacent northern hardwoods that drove the weak positive effect of lowland forest on marten occupancy (Wilton 2021). Similarly, camera sites in 2022 in northern hardwoods adjacent to the Jordan River (Wolverine Moraines) frequently detected marten and drove a strong positive effect on occupancy probability. However, camera sites in 2021 that included lowland forest types in the surrounding area did not detect marten and consequently drove a strong, and nearly significant (p-value = 0.06), negative effect on occupancy. With respect to marten habitat selection, both positive and negative associations with lowland forests may have ecological merit in the nuances of their landscape context and variation in the lowland forest types that were aggregated for a necessarily coarse occupancy analysis (i.e., low overall sample sizes). In 2021, the lowland forest areas included within camera sites that did not detect marten mostly consisted of expansive hardwood-conifer swamp and shrub thicket communities, habitats likely unsuitable for marten (Wright 1999, Buchanan 2008). In 2022, the lowland forest areas included within camera sites that detected marten mostly consisted of narrow riparian conifer and shrub thicket zones along the Jordan River. It is unclear why we observed a positive association between marten occupancy and this lowland riparian area compared to those in the 2021 survey area, but several hypotheses may simultaneously be plausible. First, the extensive northern hardwoods and steep topography surrounding the Jordan River may be more important to marten occupancy than the nearby riparian forests in and of itself, though marten have been documented foraging in riparian habitats (Tomson 1999). Additionally, the Jordan River encompasses a High Conservation Value Area (HCVA), with a Dedicated Habitat Area designation for species requiring 'interior core forest habitat', including marten, northern goshawk (*Accipiter gentilis*), and pileated woodpecker (*Dryocopus pileatus*; MDNR 2017; Appendix VI). This designation places an emphasis on the long-term conservation of these species and its influence on marten occupancy in the Jordan River study area may have confounded our observed positive relationship with lowland forest.

Conclusions & Management Recommendations

Where marten appear to have strongholds in the northern hardwood dominated Chandler Hills and Jordan River study areas, a critical question remains regarding their persistence. What proportion of the landscape can be maintained under rotational timber extraction methods (e.g., clearcut and select cut) while supporting a viable and interconnected marten population? Although marten appear to be persisting under the current management regime based on our findings, further research is needed to ascertain their status and population trajectory. The response of marten to both clearcut and selective harvesting depends largely on landscape-scale habitat suitability (e.g., FRD Management Area) and the spatial distribution of timber harvests therein contained. Forest management in marten occupied landscapes should strive to produce forest mosaics that provide marten space to shift home range areas when harvest temporarily reduces home-range scale suitability (Fuller et al. 2005, Woollard 2021). Preliminary evidence from our survey in the Wolverine Moraines suggest marten are detected less in areas with proportionally greater acreage under clearcut or select cut methods. Numerous studies across marten range in North America have found a variable, but generally decreasing, utilization response by marten to areas of habitat with greater partial harvests and recent or regenerating clearcuts (Hargis et al. 1999, Potvin et al. 2000, Fuller et al. 2005). Future occupancy analysis of these data should explicitly investigate the influence of various timber treatment methods on marten occupancy probability. Additional studies to derive abundance, survival, and fine-scale resource use in relation to past and present timber management are also needed to proactively guide marten conservation efforts in the NLP.

In summarizing forest treatment prescriptions for this study, we noted several tree harvest prescriptions in the Chandler Hills area of the Wolverine Moraines that included various silvicultural actions to create, maintain, or improve upon existing marten habitat in conjunction with timber harvest. For example, harvest treatments included the creation of desirable marten habitat by felling and leaving trees intact on the ground or leaning at an angle to increase the coarse woody debris that marten use for foraging, resting, and den site selection. Though marten are a designated Featured Species in the Chandler Hills, no Dedicated Habitat Areas exist to formally recognize critical habitat within compartments and/or stands such that marten habitat management can be prioritized in the ecologically most important areas.

We encourage harvest treatments and forest management plans to implement the marten occurrences learned from these survey efforts to help further inform and adapt silvicultural treatments to mitigate marten habitat loss and ensure occupied and unoccupied suitable habitat remains interconnected (see Appendix IV). For example, two cameras (106, 110) in compartment 52055 (YOE 2024) set in the Jordan River study area during the 2022 survey occurred within the same proposed selective cut (single tree selection), with two smaller clearcuts (no retention) occurring within their 4-km^2 buffer. One of these cameras (106) detected marten and management activities should ensure this treatment area remains suitable for marten and remains connected to occupied stands to the north (Figure 12). Additionally, camera site 106, and others that detected marten, are outside of the Dedicated Habitat Area for marten and other interior forest habitat species (Appendix VI). Extending this boundary to encompass stands with known marten detections will further encourage management actions that improve long-term marten habitat suitability.

Although we have failed to detect fisher anywhere in the study area since their initial detection in 2019, continued efforts to document fisher presence is critical for understanding whether and where this species can persist in the NLP. We recommend continued camera trap and scat detection dog surveys surrounding areas that previously detected fisher. Increasing camera trap density and/or detection dog effort may be required to increase detection probability of this rare and elusive species.

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Appendices

Appendix I. Raw camera trap site data from field data sheets (2021-2022).

Year	Site	UTM_X	UTM_Y	Set By	Setup Date	Retrieval Date	CWD Density	Detection Distance
2021	1	658654	5061111	NJ	2/1/2021	5/17/2021	11-20	30
2021	2	657105	5060049	NJ	2/1/2021	5/17/2021	20+	15
2021	3	658781	5059093	NJ	2/4/2021	5/17/2021	1-10	36
2021	4	656824	5058285	NJ	2/2/2021	5/17/2021	1-10	27
2021	5	661018	5058062	NJ	2/4/2021	5/17/2021	1-10	58
2021	6	658167	5056658	NJ	2/2/2021	5/17/2021	11-20	25
2021	7	660559	5055817	NJ	2/2/2021	5/17/2021	20+	33
2021	8	654947	5054608	BP	2/10/2021	5/20/2021	1-10	30
2021	9	649547	5050047	KH	1/28/2021	5/17/2021	20+	50
2021	10	656876	5049360	KH	2/1/2021	5/19/2021	20+	35
2021	11	668238	5049208	KH	2/4/2021	5/19/2021	20+	50
2021	12	651416	5048591	KH	1/28/2021	5/17/2021	20+	50
2021	13	654834	5048520	KH	2/2/2021	5/17/2021	20+	80
2021	14	658744	5048165	KH	2/1/2021	5/19/2021	11-20	45
2021	16	653193	5047075	KH	1/28/2021	5/17/2021	20+	45
2021	17	656911	5047081	KH	2/2/2021	5/19/2021	11-20	35
2021	18	660366	5046911	KH	2/2/2021	5/19/2021	11-20	50
2021	19	668059	5047087	KH	2/4/2021	5/19/2021	20+	50
2021	20	651243	5045805	KH	1/28/2021	5/17/2021	20+	45
2021	21	654952	5046113	KH	2/1/2021	5/17/2021	20+	80
2021	22	658770	5046103	KH	2/1/2021	5/19/2021	11-20	25
2021	23	666191	5046017	KH	2/4/2021	5/19/2021	20+	45
2021	24	653332	5044950	KH	2/1/2021	5/17/2021	20+	75
2021	25	660577	5044965	KH	2/2/2021	5/19/2021	20+	35
2021	26	651360	5044010	KH	1/28/2021	5/22/2021	20+	50
2021	28	659168	5043926	KH	1/29/2021	5/19/2021	20+	70
2021	30	653168	5042817	KH	1/28/2021	5/17/2021	20+	45
2021	31	656476	5042304	KH	2/1/2021	5/17/2021	1-10	50
2021	32	660617	5042841	KH	1/29/2021	5/19/2021	20+	45
2021	35	666204	5041744	KH	2/3/2021	5/19/2021	1-10	50
2021	36	660547	5040521	KH	1/29/2021	5/17/2021	20+	50
2021	38	658941	5039633	KH	1/29/2021	5/17/2021	11-20	40
2021	39	682889	5029655	SM	2/2/2021	5/20/2021	1-10	30
2021	40	684829	5028882	SM	2/2/2021	5/20/2021	1-10	40
2021	41	682277	5027776	KH	2/10/2021	5/20/2021	11-20	50
2021	42	684055	5026520	SM	2/2/2021	5/20/2021	1-10	25
2021	43	682996	5025620	SM	2/2/2021	5/20/2021	1-10	40

Year	Site	UTM_X	UTM_Y	Set By	Setup Date	Retrieval Date	CWD Density	Detection Distance
2021	44	680809	5024450	KH	2/10/2021	5/20/2021	11-20	35
2021	45	671471	5023641	MF	2/19/2021	5/21/2021	11-20	32
2021	46	679372	5023441	SM	2/2/2021	5/20/2021	1-10	45
2021	47	684030	5023525	KH	2/10/2021	5/20/2021	11-20	60
2021	48	673599	5022477	MF	2/2/2021	5/17/2021	11-20	31
2021	49	677369	5022587	BP	2/4/2021	5/17/2021	1-10	40
2021	50	681119	5022481	SM	2/3/2021	5/20/2021	1-10	35
2021	51	671851	5021331	MF	2/3/2021	5/18/2021	20+	50
2021	52	675374	5021301	BP	2/4/2021	5/17/2021	11-20	35
2021	53	678733	5021313	BP	2/4/2021	5/17/2021	1-10	45
2021	54	673614	5020920	BP	2/3/2021	5/17/2021	11-20	30
2021	55	677385	5020069	BP	2/2/2021	5/17/2021	20+	40
2021	56	671903	5019081	MF	2/3/2021	5/18/2021	20+	12
2021	57	675593	5019042	MF	2/12/2021	5/18/2021	1-10	27
2021	59	673696	5018058	MF	2/3/2021	5/18/2021	20+	69
2021	61	671335	5017009	BP	2/11/2021	5/21/2021	1-10	25
2021	62	675565	5016980	MF	2/4/2021	5/18/2021	20+	25
2021	63	678945	5016858	BP	2/16/2021	5/17/2021	1-10	20
2021	64	673532	5016070	BP	2/11/2021	5/21/2021	11-20	25
2021	65	677289	5015929	BP	2/16/2021	5/21/2021	11-20	25
2021	67	671767	5014898	BP	2/11/2021	5/21/2021	1-10	25
2021	68	675492	5014875	MF	2/4/2021	5/18/2021	20+	20
2021	70	673618	5013917	BP	2/11/2021	5/21/2021	11-20	20
2021	71	677623	5013915	BP	2/12/2021	5/20/2021	1-10	30
2021	72	681030	5013768	BP	2/16/2021	5/17/2021	1-10	25
2021	73	671527	5012806	BP	2/11/2021	5/21/2021	11-20	NA
2021	74	675339	5012743	BP	2/12/2021	5/20/2021	11-20	35
2021	76	682539	5012819	KH	2/12/2021	5/21/2021	20+	40
2021	77	673580	5011625	MF	2/1/2021	5/20/2021	20+	20
2021	78	677304	5011678	BP	2/12/2021	5/20/2021	1-10	40
2021	79	681556	5011648	KH	2/12/2021	5/21/2021	20+	35
2021	80	671742	5010539	MF	2/1/2021	5/20/2021	1-10	36
2021	81	679175	5010631	BP	2/16/2021	5/20/2021	1-10	30
2021	82	682543	5010614	KH	2/12/2021	5/21/2021	20+	45
2021	83	673679	5009446	MF	2/1/2021	5/20/2021	11-20	12
2021	84	677365	5009461	BP	2/12/2021	5/20/2021	1-10	30
2021	85	681462	5008704	KH	2/12/2021	5/21/2021	11-20	50
2021	86	678641	5007978	KH	2/12/2021	5/21/2021	11-20	45
2022	1	649207	5050740	KH	1/21/2022	5/23/2022	20+	30
2022	2	651591	5049910	KH	1/17/2022	5/23/2022	20+	35

Year	Site	UTM_X	UTM_Y	Set By	Setup Date	Retrieval Date	CWD Density	Detection Distance
2022	3	649832	5049580	KH	1/31/2022	5/23/2022	11-20	80
2022	4	653622	5049190	KH	1/17/2022	5/23/2022	20+	35
2022	5	651637	5048360	KH	1/17/2022	5/23/2022	20+	40
2022	6	653161	5047100	KH	1/20/2022	5/23/2022	20+	55
2022	7	651292	5045840	KH	1/20/2022	5/23/2022	11-20	30
2022	8	650335	5045490	KH	1/31/2022	5/23/2022	11-20	45
2022	9	653344	5045240	KH	1/17/2022	5/23/2022	20+	70
2022	10	651352	5043920	KH	1/21/2022	5/25/2022	20+	55
2022	11	653199	5042910	KH	1/17/2022	5/23/2022	20+	30
2022	12	651860	5042210	KH	1/17/2022	5/23/2022	11-20	50
2022	14	712684	5047180	BP	2/16/2022	6/3/2022	1-10	NA
2022	18	712704	5044710	BP	2/16/2022	6/3/2022	1-10	NA
2022	20	711393	5044240	BP	2/16/2022	6/3/2022	1-10	NA
2022	21	714516	5043880	BP	2/17/2022	6/3/2022	1-10	NA
2022	22	718343	5044130	BP	2/21/2022	6/3/2022	11-20	NA
2022	24	712688	5042870	BP	2/16/2022	6/3/2022	1-10	NA
2022	25	716431	5042830	BP	2/17/2022	6/3/2022	1-10	NA
2022	27	723888	5042900	BP	2/21/2022	6/3/2022	0	NA
2022	28	714538	5042440	BP	2/17/2022	6/3/2022	11-20	NA
2022	30	718203	5042020	BP	2/21/2022	6/3/2022	1-10	NA
2022	41	705393	5036300	BP	2/24/2022	6/1/2022	11-20	NA
2022	42	708945	5036520	BP	2/7/2022	6/1/2022	1-10	NA
2022	44	707152	5035330	BP	2/15/2022	6/1/2022	11-20	NA
2022	45	710831	5035400	BP	2/7/2022	6/1/2022	1-10	NA
2022	47	705293	5034280	BP	2/24/2022	6/1/2022	1-10	NA
2022	48	709153	5034270	BP	2/7/2022	6/1/2022	1-10	NA
2022	50	707422	5033120	BP	2/15/2022	6/1/2022	1-10	NA
2022	52	710421	5033420	BP	2/7/2022	6/1/2022	11-20	NA
2022	55	708911	5031970	BP	2/7/2022	6/1/2022	1-10	NA
2022	56	712332	5032430	BP	2/7/2022	6/1/2022	1-10	NA
2022	58	668373	5001960	KH	2/3/2022	5/26/2022	20+	50
2022	63	669043	4999890	BP	3/2/2022	5/26/2022	1-10	40
2022	66	662400	4998390	KH	3/4/2022	5/29/2022	11-20	70
2022	67	667763	4998330	KH	2/3/2022	5/26/2022	20+	35
2022	68	669910	4998140	KH	2/2/2022	5/26/2022	11-20	65
2022	69	660619	4997660	KH	3/4/2022	5/29/2022	11-20	40
2022	70	664397	4997710	KH	3/4/2022	5/29/2022	11-20	45
2022	71	671695	4997670	KH	2/2/2022	5/28/2022	11-20	55
2022	72	668440	4997310	KH	2/2/2022	5/26/2022	11-20	35
2022	73	663047	4996410	KH	3/4/2022	5/29/2022	11-20	NA

Year	Site	UTM_X	UTM_Y	Set By	Setup Date	Retrieval Date	CWD Density	Detection Distance
2022	74	669900	4996610	KH	2/2/2022	5/26/2022	11-20	60
2022	75	668625	4995520	KH	2/2/2022	5/26/2022	11-20	50
2022	77	666644	4995150	KH	2/3/2022	5/26/2022	11-20	35
2022	78	662306	4994540	KH	2/1/2022	5/28/2022	11-20	45
2022	80	660016	4993090	KH	3/3/2022	5/28/2022	20+	65
2022	81	658376	4992210	KH	2/4/2022	5/28/2022	20+	35
2022	82	662170	4992120	KH	2/4/2022	5/28/2022	11-20	45
2022	83	664590	4991830	KH	2/4/2022	5/28/2022	1-10	45
2022	84	660645	4990960	KH	2/4/2022	5/28/2022	11-20	40
2022	85	653386	4991040	KH	3/3/2022	5/29/2022	20+	45
2022	86	651726	4990220	KH	2/17/2022	5/29/2022	11-20	35
2022	87	659022	4990500	KH	2/10/2022	5/28/2022	20+	35
2022	88	662452	4990150	KH	2/3/2022	5/28/2022	1-10	60
2022	90	653142	4988900	KH	2/21/2022	5/29/2022	20+	35
2022	91	660180	4989130	KH	2/16/2022	5/28/2022	20+	40
2022	92	647625	4987370	KH	3/1/2022	5/29/2022	20+	60
2022	94	658900	4987270	KH	3/1/2022	5/29/2022	11-20	40
2022	95	655474	4986960	KH	2/25/2022	5/29/2022	20+	55
2022	99	656007	4986500	KH	3/2/2022	5/29/2022	20+	50
2022	100	660497	4986930	KH	2/10/2022	5/28/2022	11-20	60
2022	101	654368	4985920	KH	2/10/2022	5/28/2022	20+	65
2022	102	647355	4985820	KH	2/17/2022	5/29/2022	11-20	50
2022	104	655277	4985440	KH	2/23/2022	5/29/2022	20+	45
2022	105	660681	4985560	KH	2/16/2022	5/28/2022	20+	60
2022	106	654088	4983460	KH	3/2/2022	5/28/2022	20+	40
2022	107	656651	4984590	KH	2/23/2022	5/28/2022	11-20	40
2022	109	658574	4983860	KH	2/23/2022	5/28/2022	20+	45
2022	110	654556	4982760	KH	2/23/2022	5/28/2022	20+	35

Appendix II. Camera deployment and checking protocol and field data sheet.

<u>MARTEN-FISHER PROJECT - CAMERA SETTING PROTOCOL</u>

Camera Deployment

- Within about a 100-meter radius of the planned GPS point search around the GPS point until you find a location having a suitable field of view to allow martens and fishers to be photographed.
  a. Avoid placing cameras on human-use roads and trails to minimize theft/vandalism. Also try to avoid having the camera face roads/trails if possible.
  b. If the planned camera location is inaccessible, try to find an accessible location within the same or similar habitat within the grid cell, if possible.
  c. Also try to maintain at least a 1.3-mile distance between adjacent cameras, but just do the best you can. This is the center-to-center distance between adjacent grid cells.

Camera Site Details

- Set cameras facing available coarse woody debris (CWD) features that may facilitate detection. Marten often use these features for hunting and traveling during winter; large diameter logs may be better features if available and multiple stacked logs even better.
  a. Place cameras about 2–3 ft (about knee-waist height) above ground to a sturdy tree and about 10 ft from the target detection zone (e.g., log). But you can adapt this to the situation as needed (e.g., it is better to make sure you are getting a good and clear angle on the coarse woody debris feature than it is to stick to these numbers).
  b. If possible, set the camera on a tree at about a 45-degree angle to the log feature (see below photos for examples). This maximizes the time a traveling animal is within the camera's detection zone. With this set up, cameras can often be placed closer (~5 ft) from the log.
  c. Record the feature you chose to place the camera at (Set Type). This should be some kind of coarse woody debris feature (log(s), root mound/tip-up, tree snags), but if you cannot find adequate CWD, describe the type of set you used.
  d. Set cameras facing North, if possible, and record the bearing (Camera Bearing).
  e. If necessary, angle cameras slightly downward toward the target using a small stick placed between the camera and tree. This can be helpful when trying to exclude unnecessary canopy elements from the frame (see below photo examples).

Neither of these camera setups follow my 45-degree angle suggestion but were very successful at detecting marten. The complex structure (e.g., stacked logs and root masses) of the coarse woody debris in these sets was likely very attractive to marten and helped encourage them to explore the features and increase their detection probability. Note also that most of the frame is focused towards the ground, excluding much of the canopy; this maximizes the use of the sensor's full detection zone for marten.

Aiming the camera down the length of a log maximizes the likelihood an animal traveling along the log will trigger the camera's sensor.

If you find a nice log feature but cannot aim the camera down the log, make sure the camera is set far enough away to capture as much of the log as possible while still being close enough to have a marten trigger the sensor (probably about 10–15 feet depending on size of log). Both of these sets were obviously successful, but the set on the left will detect an animal over a much greater length of the target feature than the set on the right.

f. Double check your camera angle and framing by checking the view on the camera's LCD screen.
g. Clear vegetation obstructing the camera's detection zone and vegetation that may falsely trigger the camera. Check the edges of the frame as well for branches that may trigger the


This set was otherwise perfect except for this nuisance beech branch at the edge of the frame that kept triggering the sensor every time the wind blew. Most of the time this branch was not even within the frame.

sensor

h. Set the camera to Motion Test mode and walk back-and-forth in front of the camera at increasing distances from the camera. Record the approximate distance (Detection Dist) between you and the camera when the red light stops flashing (i.e., stops detecting you).

i. Circle the most appropriate Habitat Type for the location of the camera trap.

ACTIVATE THE CAMERA

1) Turn the camera on.
2) Name the camera "CAMERA ##" with the site's ID number.
3) Double check cameras are on <u>2-shot Rapidfire</u> with <u>1-sec delay</u> between triggers.
4) Double check the Date and Time stamp are correct before activating the camera.
5) Double check the camera is set to "Trail cam".
6) Navigate back to the main screen.
7) Check the angle of the camera (you can take a picture by pressing the center "E" button).

The first picture

- Once the camera is set and activated, trigger the camera by holding the whiteboard with DATE, TIME, CAMERA ID#, SD ID#, VISIT #, and your INITIALS.

<u>Camera checking protocol</u>

1) When you arrive at the camera, trigger the camera by holding the whiteboard with DATE, TIME, CAMERA ID#, SD ID#, INITIALS, and VISIT #. This step confirms to me that the camera was operational during the entire period.
2) Record the SD ID # on the datasheet, make sure it is clearly written on the SD card you are removing from the camera, and record the number of pictures taken on the datasheet.
3) Reapply lure at the site.
4) Once the camera has been loaded with the new SD card, retake the whiteboard photo with new SD ID # and Visit #. This signifies the start of the next session and is a good way to make sure the camera is operational before leaving.

Example of whiteboard photo taken at first deployment, camera maintenance checks, and camera retrieval. This shows that the camera was functional at the beginning and end of a deployment period and provides enough data to correct any date/time stamp or site naming errors.

LTBB ODAWA CAMERA TRAP DATASHEET 2019

CAMERA DEPLOYMENT		
Observer Initials:		
Camera ID:		***SD ID:
Planned UTMs:	E:	N:
Actual UTMs:	E:	N:
Waypoint ID:		

HABITAT	
Horizontal cover density: shrub/tree	None / Low / Med / High
Coarse Woody Debris:	None / Low / Med / High
Other natural/human features: *E.g., timber harvest, power line cut, topography, windthrow, wet soils, etc.	

CAMERA SITE DETAILS	*E.g., game trail, ORV trail, stream, river, pond
Set Type:	Trail / Water / Log / Other:
Set Type Details*:	
Mount:	Tree / Other:
Camera Bearing:	
Detection Dist (ft):	

DOMINANT VEGETATION
Canopy:
Sub-canopy:

Visit	Initials	Date	Time (military)	**** SD ID	Cam Status	# of images	Battery life	Lure type	Notes (malfunctions, vandalism, cam moved by animals, animal sign, weather, other observations) *more space on back of page

Appendix III. Model selection results for 2021 marten occupancy analyses ranked in order of decreasing AIC support (competing models have ΔAIC < 2.00). Number of model parameters (K), Akaike's Information Criterion (AIC), the difference in AIC between the top-supported model and the i th ranked model (ΔAIC), model weight (w_i), and cumulative model weight (cuml. w_i) are presented for each candidate model. Only models with ΔAIC ≤ 3.0 are displayed (64 total models). All models included the abundance of coarse woody debris (CWD) as a covariate on marten detection probability (not displayed).

Formula (2021 survey)	K	AIC	ΔAIC	w_i	cuml. w_i
Ψ(LF + MF + UCF)	6	615.5	0.0	0.08	0.08
Ψ(LF + MF + MTP + UCF)	7	615.5	0.1	0.08	0.17
Ψ(LF + MF + UDF)	6	615.9	0.4	0.07	0.24
Ψ(LF + MTP + UCF)	6	616.4	1.0	0.05	0.29
Ψ(LF + UCF)	5	616.5	1.0	0.05	0.34
Ψ(Forest Cover + LF + MTP + UCF + UDF)	8	616.8	1.3	0.04	0.38
Ψ(Forest Cover + LF + MF + UDF)	7	617.0	1.5	0.04	0.42
Ψ(LF + UDF)	5	617.0	1.5	0.04	0.46
Ψ(LF + MF + MTP + UCF + UDF)	8	617.5	2.0	0.03	0.50
Ψ(Forest Cover + LF + MF + UCF)	7	617.5	2.0	0.03	0.53
Ψ(LF + MF + MTP + UDF)	7	617.5	2.0	0.03	0.56
Ψ(Forest Cover + LF + MF + MTP + UCF)	8	617.5	2.1	0.03	0.59
Ψ(LF + MTP + UCF + UDF)	7	617.9	2.4	0.03	0.61
Ψ(LF + MTP + UDF)	6	618.0	2.6	0.02	0.64
Ψ(Forest Cover + MF + UDF)	6	618.2	2.7	0.02	0.66
Ψ(LF)	4	618.4	2.9	0.02	0.68
Ψ(Forest Cover + LF + MTP + UCF)	7	618.4	3.0	0.02	0.70
Ψ(Forest Cover + LF + MTP + UCF)	7	618.4	3.0	0.02	0.72
Ψ(LF + UCF + UDF)	6	618.4	3.0	0.02	0.74
Ψ(Forest Cover + LF + MF + UCF + UDF)	8	618.5	3.0	0.02	0.75

LF = Lowland Forest
MF = Mixed Forest
MTP = Managed Tree Plantation
UCF = Upland Conifer Forest
UDF = Upland Deciduous Forest

Appendix III. Model selection results for 2022 marten occupancy analyses...

Formula (2022 survey)	K	AIC	ΔAIC	wi	cuml. w_i
Ψ(MTP + UDF)	5	289.4	0.0	0.08	0.08
Ψ(LF + UDF)	5	289.5	0.1	0.08	0.16
Ψ(LF + MF + MTP + UDF)	7	289.5	0.1	0.08	0.23
Ψ(Forest Cover + MF + MTP + UDF)	7	289.6	0.1	0.07	0.31
Ψ(MF + MTP + UCF + UDF)	7	290.1	0.7	0.06	0.36
Ψ(Forest Cover + UDF)	5	290.6	1.1	0.05	0.41
Ψ(Forest Cover + UCF)	5	290.8	1.4	0.04	0.45
Ψ(Forest Cover + MTP + UDF)	6	291.0	1.5	0.04	0.48
Ψ(MF + UDF)	5	291.1	1.6	0.04	0.52
Ψ(Forest Cover + MTP + UCF)	6	291.2	1.7	0.03	0.55
Ψ(LF + MF + UDF)	6	291.3	1.9	0.03	0.58
Ψ(MF + MTP + UDF)	6	291.4	1.9	0.03	0.61
Ψ(Forest Cover + LF + UDF)	6	291.5	2.1	0.03	0.64
Ψ(MTP + UCF)	5	291.5	2.1	0.03	0.67
Ψ(Forest Cover + UCF + UDF)	6	291.6	2.1	0.03	0.70
Ψ(Forest Cover + LF + MTP + UCF)	7	291.8	2.4	0.02	0.72
Ψ(Forest Cover + LF + UCF)	6	292.1	2.6	0.02	0.74
Ψ(UCF)	4	292.1	2.7	0.02	0.76
Ψ(Forest Cover + MF + UCF)	6	292.3	2.8	0.02	0.78

LF = Lowland Forest
MF = Mixed Forest
MTP = Managed Tree Plantation
UCF = Upland Conifer Forest
UDF = Upland Deciduous Forest

Appendix IV. Michigan Forest Inventory (MiFI) stand data associated with camera trap site locations and marten detections.

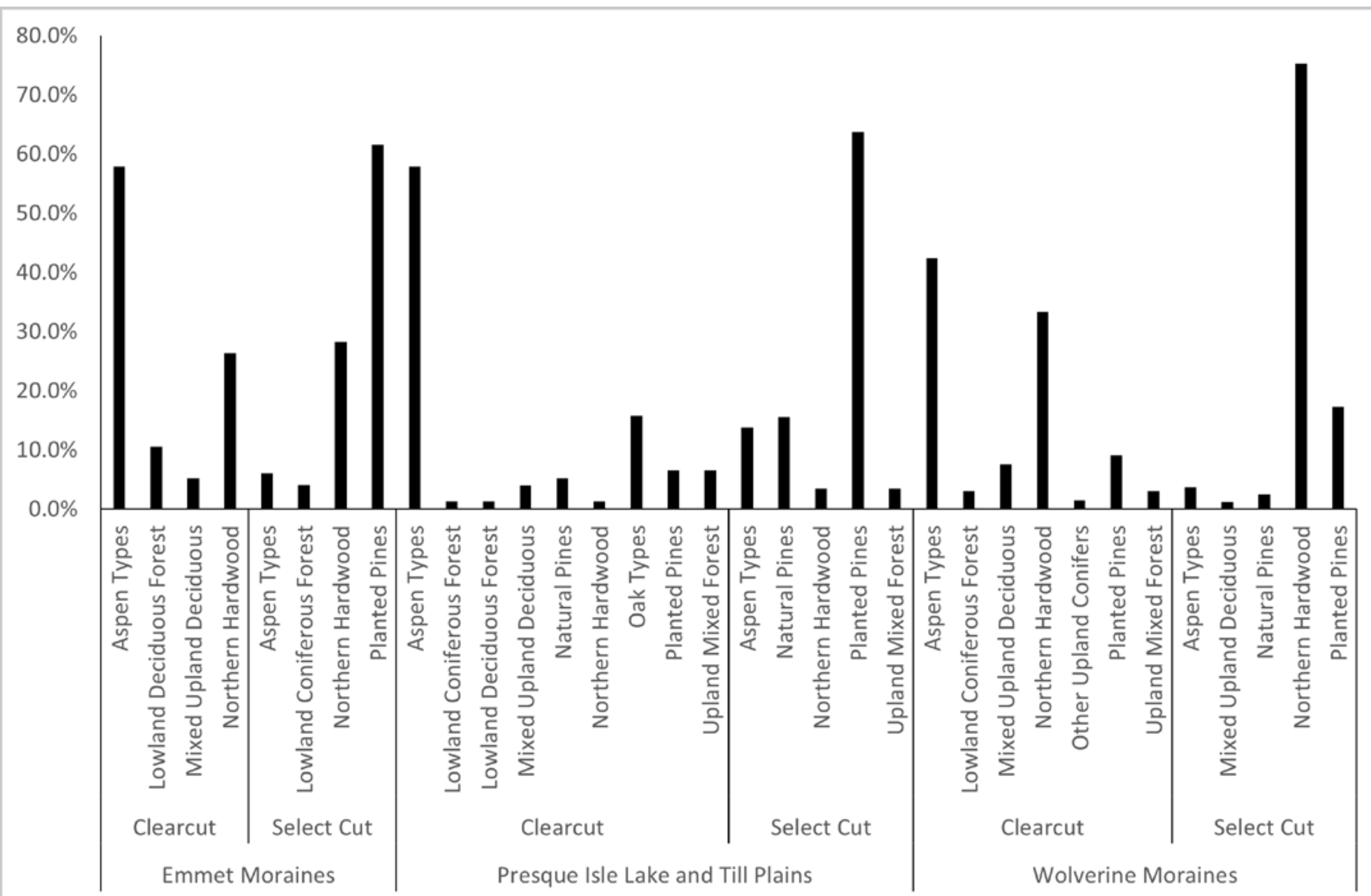
Year	Site	Marten Detec-tions	FRD Mgmt. Area	FC Key	Stand	Year Of Entry	Canopy Closure	Size	BA Range	L4 Cover Type	L3 Cover Type
2021	9	1	Emmet Moraines	52101	3	2024	75-100	Log	81-110	Other Mixed Upland Deciduous	Mixed Upland Deciduous
2021	12	1	Emmet Moraines	52101	12	2024	50-75	Log	51-80	Sugar Maple Association	Northern Hardwood
2021	14	2	Emmet Moraines	52110	19	2016	75-100	Log	51-80	Sugar Maple Association	Northern Hardwood
2021	18	1	Emmet Moraines	52110	29	2016	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2021	22	1	Emmet Moraines	52111	3	2023	75-100	Log	51-80	Sugar Maple Association	Northern Hardwood
2021	46	3	Wolverine Moraines	52143	42	2017	75-100	Log	81-110	S.Maple, Hard Mast Association	Northern Hardwood
2021	48	7	Wolverine Moraines	52129	8	2024	75-100	Log	111-140	Sugar Maple Association	Northern Hardwood
2021	49	2	Wolverine Moraines	52129	26	2024	75-100	Log	111-140	Sugar Maple Association	Northern Hardwood
2021	50	1	Wolverine Moraines	52150	59	2016	75-100	Pole	111-140	Planted Red Pine	Planted Pines
2021	52	2	Wolverine Moraines	52129	21	2024	75-100	Log	141-170	Sugar Maple Association	Northern Hardwood
2021	53	7	Wolverine Moraines	52144	1	2022	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2021	54	7	Wolverine Moraines	52129	25	2024	75-100	Log	51-80	Sugar Maple Association	Northern Hardwood
2021	55	3	Wolverine Moraines	52128	55	2016	75-100	Pole	51-80	Aspen	Aspen Types
2021	56	4	Wolverine Moraines	52216	4	2021	75-100	Log	111-140	Sugar Maple Association	Northern Hardwood
2021	57	2	Wolverine Moraines	52128	36	2016	75-100	Pole	51-80	Mixed Northern Hardwoods	Northern Hardwood

Year	Site	Marten Detec-tions	FRD Mgmt. Area	FC Key	Stand	Year Of Entry	Canopy Closure	Size	BA Range	L4 Cover Type	L3 Cover Type
2021	59	4	Wolverine Moraines	52216	31	2021	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2021	62	8	Wolverine Moraines	52034	4	2018	75-100	Pole	111-140	Sugar Maple Association	Northern Hardwood
2021	63	2	Wolverine Moraines	52145	7	2018	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2021	64	1	Wolverine Moraines	52035	9	2016	75-100	Pole	81-110	Sugar Maple Association	Northern Hardwood
2021	65	10	Wolverine Moraines	52034	29	2018	75-100	Log	81-110	S.Maple, Hard Mast Association	Northern Hardwood
2021	67	8	Wolverine Moraines	52035	9	2016	75-100	Pole	81-110	Sugar Maple Association	Northern Hardwood
2021	68	1	Wolverine Moraines	52034	33	2018	75-100	Log	51-80	Sugar Maple Association	Northern Hardwood
2021	70	4	Wolverine Moraines	52035	26	2016	75-100	Pole	51-80	Sugar Maple Association	Northern Hardwood
2021	71	4	Wolverine Moraines	52034	47	2018	75-100	Log	51-80	Sugar Maple Association	Northern Hardwood
2021	72	1	Wolverine Moraines	52155	24	2018	75-100	Log	111-140	Planted Red Pine	Planted Pines
2021	74	1	Wolverine Moraines	52034	42	2018	75-100	Log	81-110	Mixed Northern Hardwoods	Northern Hardwood
2021	77	31	Wolverine Moraines	52042	136	2020	75-100	Log	111-140	Red Oak	Oak Types
2021	82	3	Wolverine Moraines	52157	32	2023	75-100	Pole	81-110	S.Maple, Hard Mast Association	Northern Hardwood
2021	83	4	Wolverine Moraines	52042	45	2020	75-100	Log	81-110	Other Mixed Upland Deciduous	Mixed Upland Deciduous
2022	66	1	Wolverine Moraines	52044	96	2025	75-100	Log	51-80	Sugar Maple Association	Northern Hardwood

Year	Site	Marten Detec-tions	FRD Mgmt. Area	FC Key	Stand	Year Of Entry	Canopy Closure	Size	BA Range	L4 Cover Type	L3 Cover Type
2022	67	1	Wolverine Moraines	52044	112	2025	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2022	68	1	Wolverine Moraines	52033	25	2022	75-100	Pole	111-140	Sugar Maple Association	Northern Hardwood
2022	69	1	Wolverine Moraines	52046	19	2021	75-100	Log	111-140	Sugar Maple Association	Northern Hardwood
2022	70	2	Wolverine Moraines	52045	6	2022	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2022	71	1	Wolverine Moraines	52033	48	2022	75-100	Log	111-140	Sugar Maple Association	Northern Hardwood
2022	72	7	Wolverine Moraines	52045	95	2022	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2022	74	3	Wolverine Moraines	52033	15	2022	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2022	80	1	Wolverine Moraines	52049	12	2016	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood
2022	81	2	Wolverine Moraines	52050	11	2017	75-100	Log	81-110	Mixed Northern Hardwoods	Northern Hardwood
2022	88	1	Wolverine Moraines	52047	31	2025	25-50	Log	81-110	Planted Red Pine	Planted Pines
2022	91	1	Wolverine Moraines	52049	35	2016	75-100	Pole	81-110	Maple, Beech, Cherry Association	Northern Hardwood
2022	94	2	Wolverine Moraines	52058	11	2021	75-100	Log	111-140	Mixed Northern Hardwoods	Northern Hardwood
2022	95	4	Wolverine Moraines	52056	1	2025	75-100	Pole	111-140	Mixed Northern Hardwoods	Northern Hardwood
2022	100	2	Wolverine Moraines	52059	52	2024	75-100	Pole	81-110	Sugar Maple Association	Northern Hardwood
2022	104	4	Wolverine Moraines	52056	24	2025	75-100	Log	111-140	Mixed Northern Hardwoods	Northern Hardwood

Year	Site	Marten Detec-tions	FRD Mgmt. Area	FC Key	Stand	Year Of Entry	Canopy Closure	Size	BA Range	L4 Cover Type	L3 Cover Type
2022	106	1	Wolverine Moraines	52055	22	2024	75-100	Log	81-110	Mixed Northern Hardwoods	Northern Hardwood
2022	109	4	Wolverine Moraines	52058	47	2021	75-100	Log	81-110	Sugar Maple Association	Northern Hardwood

Appendix V. Percent of clearcut and select cut MiFI cover types within FRD management areas. Percentages based on the sum of 4-km^2 circular buffers (i.e., camera site areas) within each management area.



Appendix VI. Marten daily detections in the Jordan River study area (Wolverine Moraines) in relation to timber harvests and High Conservation Value Areas (Dedicated Habitat Area - interior core forest habitat).