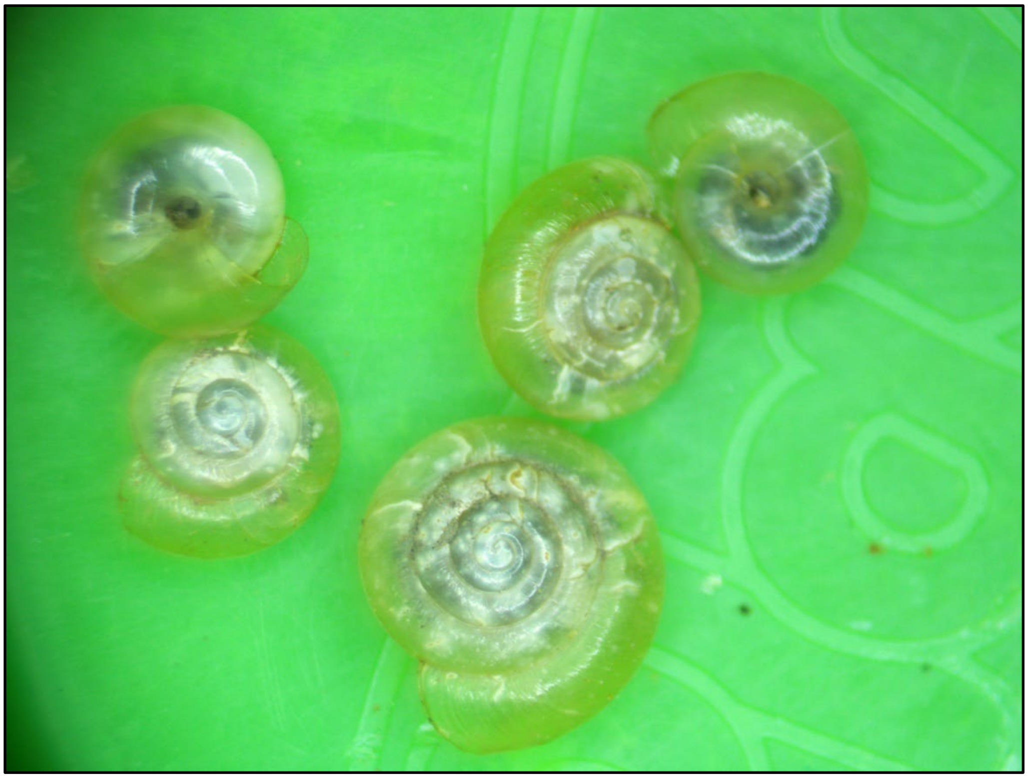
Land Snail Surveys Informed by Habitat Suitability Models at Fort Custer Training Center

Prepared by:
Ashley A. Cole-Wick, Dan J. Earl, Courtney N. Ross, Peter J. Badra
Michigan Natural Features Inventory
Michigan State University Extension
P.O. Box 13036
Lansing, MI 48901-3036

Prepared for:
Michigan Department of Military and Veteran Affairs
March 31, 2023
MNFI Report Number 2023-10



Suggested Citation:

Cole-Wick, A.A., D.J. Earl, C.N. Ross, P.J. Badra. 2023. Land Snail Surveys Informed by Habitat Suitability Models at Fort Custer Training Center. Michigan Natural Features Inventory Report Number 2023-10, Lansing, MI.

Cover Photo: Upland pillsnail (*Euchemotrema fraternum*) is a native land snail species with a shell covered in fine bristles. This ventral view shows the aperture, which holds a single blade-like tooth, or lamella. This species was one of the larger snails (scale bars showing millimeters) observed at Fort Custer Training Center in 2022.

Above Photo: Quick gloss (*Zonitoides arboreus*) was the most observed snail species at Fort Custer Training Center.

Michigan State University occupies the ancestral, traditional, and contemporary lands of the Anishinaabeg – Three Fires Confederacy of Ojibwe, Odawa, and Potawatomi peoples. The university resides on land ceded in the 1819 Treaty of Saginaw.

Table of Contents

List of Figures

List of Tables

ACKNOWLEDGEMENTS

This project was funded by the Michigan Department of Military and Veteran Affairs. The staff at the Fort Custer Training Center Environmental Department are incredible in so many ways. Thank you to Brian Huggett, Michele Richards, and Curt Roebuck for securing access and facility use, and remaining engaged and interested in the outcome of our work. Thank you to the following people for their assistance with field and laboratory work: Marta Springer, Eric Branch, Lydia Mehlhose, Mirabai Moseley, Nathan Hilbrands, Molly Fava, Charlotte Brennan, Caitlin Ott-Conn, and Clay Wilton. We thank Jeff Nekola and Kathryn Perez for assistance in confirming species identifications. Ashley Adkins, Sarah Carter, Brian Klatt, Mike Monfils, and Deb Richardson provided much appreciated administrative support for this project.

ABSTRACT

Fort Custer Training Center (FCTC) is a National Guard Training Center in southwest Michigan that serves as a large center of biodiversity in a highly fragmented landscape. Michigan Natural Features Inventory (MNFI) scientists sought to use previously collected natural community data to identify special status animal species that may occur in FCTC. To determine survey priorities, we developed habitat suitability models for a range of rare invertebrates with data collected by MNFI ecologists and botanists as part of the Michigan Forest Inventory (MiFI) surveys. After discussing potential surveys with FCTC environmental staff, we selected land snails as the focus for this study as they are a highly understudied taxon, and though many species have potential to occur at FCTC, no records have been documented. This led to a two-year study in which we surveyed common and rare land snail species in upland forests. We sampled 59 survey plots across 19 forested stands. We also collected habitat composition variables that may influence the presence of land snails. During two years of visual surveys and litter collection surveys, we collected 820 snails representing 31 confirmed species, including two species of Special Concern in Michigan. We found that land snail species abundance and richness could not be predicted with the coarse scale environmental factors we used in from MiFI data, but that land snail richness persists in natural areas of varying quality. Our results show that FCTC harbors significant land snail diversity, in addition to previously documented rare aquatic snails. Our study focused on land snails living in upland forests, and we recommend that future work on land snails continue to include these systems, but also focus on lowland natural communities, such as rich tamarack swamp, prairie fen, and southern hardwood swamp.

INTRODUCTION

Fort Custer Training Center (FCTC) is a federally owned, active National Guard Training Center operated by the Michigan Department of Military and Veteran Affairs (DMVA). It is located on 7,570 contiguous acres in eastern Kalamazoo and western Calhoun Counties in southwestern Michigan between Kalamazoo and Battle Creek. Most military training is concentrated in the northern 10% of FCTC and the remaining portion is managed for biodiversity conservation. As such, FCTC is regionally important as a contiguous block of habitat in the predominantly fragmented landscape of southern Michigan. Situated along a series of low morainal ridges in the Kalamazoo River watershed, the uplands and lowlands in FCTC support both high-quality and degraded examples of dry-mesic southern forest, oak barrens, emergent marsh, southern shrub-carr, and southern hardwood swamp that historically dominated the landscape (Cohen et al. 2020). The headwaters of two tributaries to the Kalamazoo River are found within FCTC, as well as large portions of surrounding uplands that can be managed to protect these headwaters. Given this wealth of natural resources and a long history of prescribed fire and invasive species management, FCTC supports incredible biodiversity, including many rare plant and animal species as well as rare high-quality natural communities (Cohen et al. 2009, Bassett et al. 2022).

From 2018 to 2021, ecologists from the Michigan Natural Features Inventory (MNFI) completed surveys for high-quality natural communities and vegetation mapping at FCTC using the Michigan Forest Inventory (MiFI) framework (Bassett et al. 2022). These data presented an opportunity to develop habitat suitability models to guide surveys for rare animal species. In this study, we used MiFI data to develop models to identify potentially suitable habitat for rare species with a probability of occurring at FCTC. These models provided spatial data to select sites for rare land snails within FCTC, as this group has been under-surveyed at the installation. In Michigan, 41 species of land snails are listed as either State Endangered (9 species), State Threatened (7 species), or are species of Special Concern (25 species; Derosier et al. 2015, MNFI 2023). Of the 18 species of land snails with federal listing in the US (6 Threatened, 12 Endangered); none are known to be present in Michigan, but with a lack of statewide survey it is possible that some may occur in our state (USFWS 2023). Prior to this study there were no known occurrences of any listed land snail species at FCTC in Michigan’s Natural Heritage Database (INRMP 2020, Bassett et al. 2022). Land snails are an important component of most terrestrial ecosystems, serving as food for salamanders, small mammals, birds, and some arthropods; as well as processing decaying plant material (Barker 2001). Land snails may also serve as useful biological indicators of soil quality and chemistry, especially on the microhabitat level, as snails only move small distances each year (Burch and Pearce 1990, Overton et al. 2009). This group has 24,000 described species, with an additional estimated 11,000 to 40,000 undescribed species (Lydeard et al. 2004).

The DMVA approved funding for this work in two parts – during the first part MNFI focused on determining potential rare species that may occur at FCTC and creating 26 habitat models and initiating snail surveys. The second part facilitated completion of snail surveys, with dramatically increased survey effort and associated data analysis. After examining preliminary model results and consulting FCTC Environmental staff in 2021, we focused this study on land snails, as there were no previous surveys at the installation (INRMP 2020, Bassett et al. 2022).

The goals of this project were to 1) create habitat suitability models using existing stand-level data (Bassett et al. 2022) for rare species that could occur within the installation, and 2) use these models to generate baseline data on land snails at FCTC, including documentation of rare species populations, distribution of land snail taxa, and identifying natural areas that support diverse land snail communities. In this report we briefly describe MiFI surveys and habitat suitability models, then detail land snail survey methods. Finally, we present results and discuss how land snail survey findings can be used to guide land management and conservation activities on the installation.

METHODS

The Michigan Forest Inventory (MiFI) framework is a forestry protocol that classifies forest stands into a hierarchical land cover classification. It was developed to prioritize management decisions primarily on lands owned or managed by the Michigan Department of Natural Resources and has been adapted by MNFI for comprehensive surveys on partners' lands (e.g., Cole-Wick et al. 2020, Bassett et al. 2022). Between 2018 and 2021, MNFI staff collected stand-level data using the MiFI framework in four fields: stand summary, canopy, sub-canopy, and comments (Bassett et al. 2022). Stands are polygons that represent relatively homogenous areas of a similar vegetation cover type across the landscape. The stand summary characterizes canopy closure, average tree size, stand age based on the age of the dominant tree species, whether a stand is planted vs. natural, and whether a stand is upland vs. lowland. Canopy and sub-canopy plant species were recorded to further characterize each stand. Finally, surveyors assigned an MNFI natural community type and EcoScore to each stand (Appendix A; Cohen et al. 2020). A natural community is an assemblage of interacting plants, animals, and other organisms that repeatedly occurs under similar environmental conditions across the landscape and is predominantly structured by natural processes rather than modern anthropogenic disturbances (Cohen et al. 2020). The EcoScore is a field-based classification system for defining the ecological integrity or quality of a stand based on its assigned natural community type, where 0 represents a severely degraded condition and 5 represents a minimally degraded, high-quality condition (Appendix A).

We identified 134 rare animal species for potential habitat suitability models and subsequent surveys, comprising 58 vertebrates and 78 invertebrates (Appendix B). These species either had a range that included Kalamazoo and Calhoun Counties or have been detected in the surrounding nine counties in southwest Michigan. Through a multi-step process, we narrowed down the list to 26 species for modeling. We began this process by removing vertebrate species from the list as there has been ongoing survey effort for vertebrate species, especially avian species, at FCTC over recent years (INRMP 2020, Cole-Wick et al. 2022). Conversely, many groups of invertebrates have not had focused studies at FCTC (INRMP 2020). Next, we removed species from the list that had no probability of occurring at FCTC due to a lack of habitat (Appendix B). After completing this initial selection process, 26 species remained for which we developed habitat suitability models (Table 1).

The foundational unit of the species models were stands in the Michigan Forest Inventory (MiFI) Database. No weights were given, as the main criteria for each model was the feasibility of identifying potential habitat using the ecological attributes within from MiFI. Host plant presence within a MiFI stand was the main indicator of potential habitat. In some cases, no host plant information was available, so we used a proxy, such as the natural community in which the host plant is commonly found. For example, the host plants for Kansas prairie leafhopper (*Dorydiella kansana*, Special Concern) are various species of nut-rushes (*Scleria* spp.), which were not documented during MiFI surveys, so we substituted habitat type for host plant in the model. For other species with no host plant requirements, we used surrogate variables. These surrogate variables included mature forested stands (≥120 years old) and high-quality habitat (≥ 4 EcoScore) for land snails, or a permanent connection to a stream or water feature and high-quality habitat (≥ 3.5 EcoScore, Table 1) for Odonate species.

The habitat suitability models focused on species with a potential to occur at FCTC (Table 1). To determine which species/taxa would be selected for our surveys we systematically vetted possible target species. We first removed several species that have been recently documented at FCTC, as the goal of this project is to document new species or taxa at the installation. Recently surveyed species included: odonates (i.e., tiger spiketail, *Cordulegaster erronea,* State Threatened), freshwater mussels, aquatic snails (i.e., watercress snail, *Fontigens nickliniana*, Special Concern), borer moths (*Papaipema* spp.), butterflies, and bumble bees (e.g., O'Brien et al. 2017, Cole-Wick 2018, Bassett et al. 2022, Eckhardt et al. 2022).

After examining the remaining model outputs from Table 1, we consulted with FCTC land managers to determine survey species. We decided to focus 2021-2022 survey efforts on the most under-sampled group with potential to occur at FCTC: land snails. They are an understudied taxon with no previous studies at the installation (INRMP 2020, Bassett et al. 2022) and non-marine mollusks are one of the most critically imperiled groups of animals on earth (Lydeard et al. 2004). We identified 14 forest stands for land snail surveys through the model. Since land snail ecology is poorly understood, we also included five randomly selected reference forested stands that did not fit criteria of mature (stand age ≥ 120 year), high quality (EcoScore ≥ 4) stands. These reference stands would allow us to examine if snail diversity and/or abundance is higher in high-quality forests. All reference and model predicted stands were stands with "Log" sized forests (i.e., the majority of trees in the canopy have a DBH of 10-18"). The 14 model predicted stands were all aged 120 or more years with an EcoScore ≥ 4 and the five reference stands were randomly selected and varied in both age (50 to 109 years), and EcoScore (1.5-4; Table 2). Natural communities for all stands were dry-mesic or mesic southern forest, except for one stand that was classified as a southern hardwood swamp found between two upland slopes. Stands varied in size from 5.2 to 28.6 acres, so to standardize surveys, stands were tessellated into a grid of 10m^2 to select survey locations.

Table 1. Habitat suitability models for 26 species using Michigan Forest Inventory data collected by Michigan Natural Features Inventory botanists and ecologists (Bassett et al. 2022).

Common Name	Scientific Name	State Status	Model input	# of stands
Land snails				
A land snail	*Catinella protracta*	T	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Domed disc	*Discus patulus*	SC	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Cherrystone drop	*Hendersonia occulta*	T	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Median striate	*Striatura meridionalis*	SC	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Yellow globelet	*Mesodon clausus*	SC	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Copper button	*Mesomphix cupreus*	SC	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Flat dome	*Ventridens suppressus*	SC	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Honey vertigo	*Vertigo tridentata*	SC	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Insects				
Six-banded longhorn beetle	*Dryobius sexnotatus*	T	Forested, stand age ≥120 yr, EcoScore ≥ 4	14
Tamarack tree cricket	*Oecanthus laricis*	SC	Presence of tamarack (*Larix laricina*)	1
Frosted elfin	*Callophrys irus*	T	Presence of wild lupine (*Lupinus perennis*)	4
Persius duskywing	*Erynnis persius persius*	T	Presence of wild lupine (*Lupinus perennis*)	4
Henry's elfin	*Incisalia henrici*	T	Presence of blueberry (*Vaccinium* spp.), (*Viburnum* spp.), or redbud (*Cercis canadensis*)	3
Pipevine swallowtail	*Battus philenor*	SC	Presence of pipevine (*Aristolochia* spp.) or ginger (*Asarum* spp.)	4
Three-staff underwing	*Catocala amestris*	E	Presence of leadplant (*Amorpha canescens,* Special Concern)	1
Quiet underwing	*Catocala dulciola*	SC	Presence of hawthorns (*Crataegus* spp.) and ecoscore ≥ 3.5	1
Magdalen underwing	*Catocala illecta*	SC	Presence of honey locust (*Gleditsia triacanthos*)	4
Angular spittlebug	*Lepyronia angulifera*	SC	Presence of *Eleocharis* spp.	3
Leadplant moth	*Schinia lucens*	E	Presence of leadplant (*Amorpha canescens,* Special Concern*)*	1

Regal fritillary	*Speyeria idalia*	E	Presence of birds-foot violet (*Viola pedata*)	3
Kansas prairie leafhopper	*Dorydiella kansana*	SC	Presence of prairie fen	10
Ottoe skipper	*Hesperia ottoe*	T	Presence of little bluestem *(Schizachyrium scoparium) or* big bluestem *(Andropogon gerardii*), prairie, open land with EcoScore ≥ 3	2
Great Plains spittlebug	*Lepyronia gibbosa*	SC	Presence of prairie, open land, EcoScore ≥ 3.5	3
Newman's brocade	*Meropleon ambifusca*	SC	Presence of prairie fen	10
Tiger spiketail	*Cordulegaster erronea*	SC	Connected to stream / water feature, EcoScore ≥ 3.5	17
Grey petaltail	*Tachopteryx thoreyi*	T	Connected to stream / water feature, EcoScore ≥ 3.5	17

Table 2. Michigan Forest Inventory stands selected for the land snail sampling. Stands predicted by the model had a tree age ≥ 120 years and EcoScore ≥ 4 (n=14) and randomly selected reference stands (n=5) varied in age and EcoScore. MUD* = Mixed Upland Deciduous

	EcoScore	**Age Class**	**MiFI Cover Type**	**Acres**	**Stand**	**Training Area**	**Natural Community Type**
Predicted by Model	4	120-129	Oak	13.1	45	TA04	Mesic Southern Forest
	4	120-129	MUD*	19	130	TA01	Dry-Mesic Southern Forest
	4.5	120-129	MUD*	7.4	72	TA07	Dry-Mesic Southern Forest
	5	130-139	MUD*	12.7	69	TA09	Dry-Mesic Southern Forest
	4	150+	MUD*	9.2	35	TA03	Dry-Mesic Southern Forest
	5	150+	MUD*	14	24	TA04	Mesic Southern Forest
	5	150+	MUD*	6.1	36	TA08	Dry-Mesic Southern Forest
	4	150+	MUD*	8	82	TA09	Dry-Mesic Southern Forest
	4	150+	MUD*	11.8	32	TA04	Dry-Mesic Southern Forest
	4	150+	MUD*	5.5	55	TA03	Dry-Mesic Southern Forest
	4	150+	MUD*	5.2	91	TA09	Dry-Mesic Southern Forest
	4	150+	Oak	13.3	62	TA09	Dry-Mesic Southern Forest
	4.5	150+	Oak	8.5	63	TA05	Dry-Mesic Southern Forest
	4	150+	Lowland Deciduous	4.1	62	TA03	Southern Hardwood Swamp
Reference	2	40-49	MUD*	22.1	2	TA05	Dry-Mesic Southern Forest
	1.5	50-59	MUD*	28.6	41	TA09	Dry-Mesic Southern Forest
	2	70-79	MUD*	17	15	TA04	Dry-Mesic Southern Forest
	3	70-79	MUD*	9.9	47	TA04	Dry-Mesic Southern Forest
	4	100-109	Oak	5.6	46	TA03	Dry-Mesic Southern Forest

Land Snail Surveys

Many snails were found on or near decaying woody debris during visual searches.

Within the 19 predicted (14) and reference (5) stands we overlaid a 10m^2 grid that provided a framework for standardized survey plots. Survey plots within a stand were chosen while in the field based on the presence of downed logs, boulders, moss, or other microhabitat suitable for land snails. Snails are most likely to be found under the bark of trees, near bases of rocks, under logs, and in other microhabitats that might be missed in a completely random selection of samples, so presence of these features were favored when searching plots (Pearce and Örstan 2006). At each plot we recorded the GPS coordinates, the forest stand ID, and the plot identification code (Figure 1). We characterized the groundcover by recording percent cover of vegetation, leaf litter, downed wood, moss, and bare ground within the surveyed areas (Appendix C1, C2).

In 2021 we surveyed 15 plots and in 2022 we surveyed 44 plots (Figure 1). We surveyed a total of 59 plots across 19 predicted and reference stands across the two years of this project.

We used two methods to survey each plot: visual searches and ground litter samples. First, we conducted a 60-minute visual search of the microhabitat at each plot, looking for both live snails and spent (empty) shells. All spent shells were collected into vials, and all live snails were preserved in vials with 70% ethanol solution for later identification in a laboratory. Many common and rare snail species are minute, measuring less than 2 mm in the largest shell dimension; including rare species survey targets like honey vertigo (*Vertigo tridentata,* Special Concern) and median striate (*Striatura meridionalis,* Special Concern). Therefore, visual detection of these minute specimens is highly unlikely, so to accurately assess land snail populations within each plot, we collected litter samples. We collected five ground litter samples per plot, for a total of 295 litter samples, each consisting of approximately 0.75 L of leaves, twigs, moss, soil, and/or bark. These samples were placed in a paper bag and labeled in the field. We then dehydrated all litter samples at 170 degrees for 1-3 hours, or until fully desiccated. Snail shells were then sorted from organic and inorganic particles under a stereo microscope at 10 x magnification. Each shell was separated from litter and placed into a vial for identification.

All specimens were identified in the laboratory under a 0-10 x magnification for larger snails (>10 mm), and 20-60 x magnification for smaller snails (<10 mm). We used a variety of resources to identify specimens including a dichotomous key using shell characters developed by Nekola (2003). In addition, due to congener species often having incredibly minute differences, MNFI scientists reached out to several land snail researchers to gain consensus on identifications for species through sharing of magnified photos (Figure 2). Some specimens were too damaged to accurately identify to species and were recorded as unknown partial shells when there were large enough fragments to clearly identify a unique individual. Some collected snails were immature and had not developed the structures and characteristics necessary to identify to species and were recorded as an unknown juvenile.

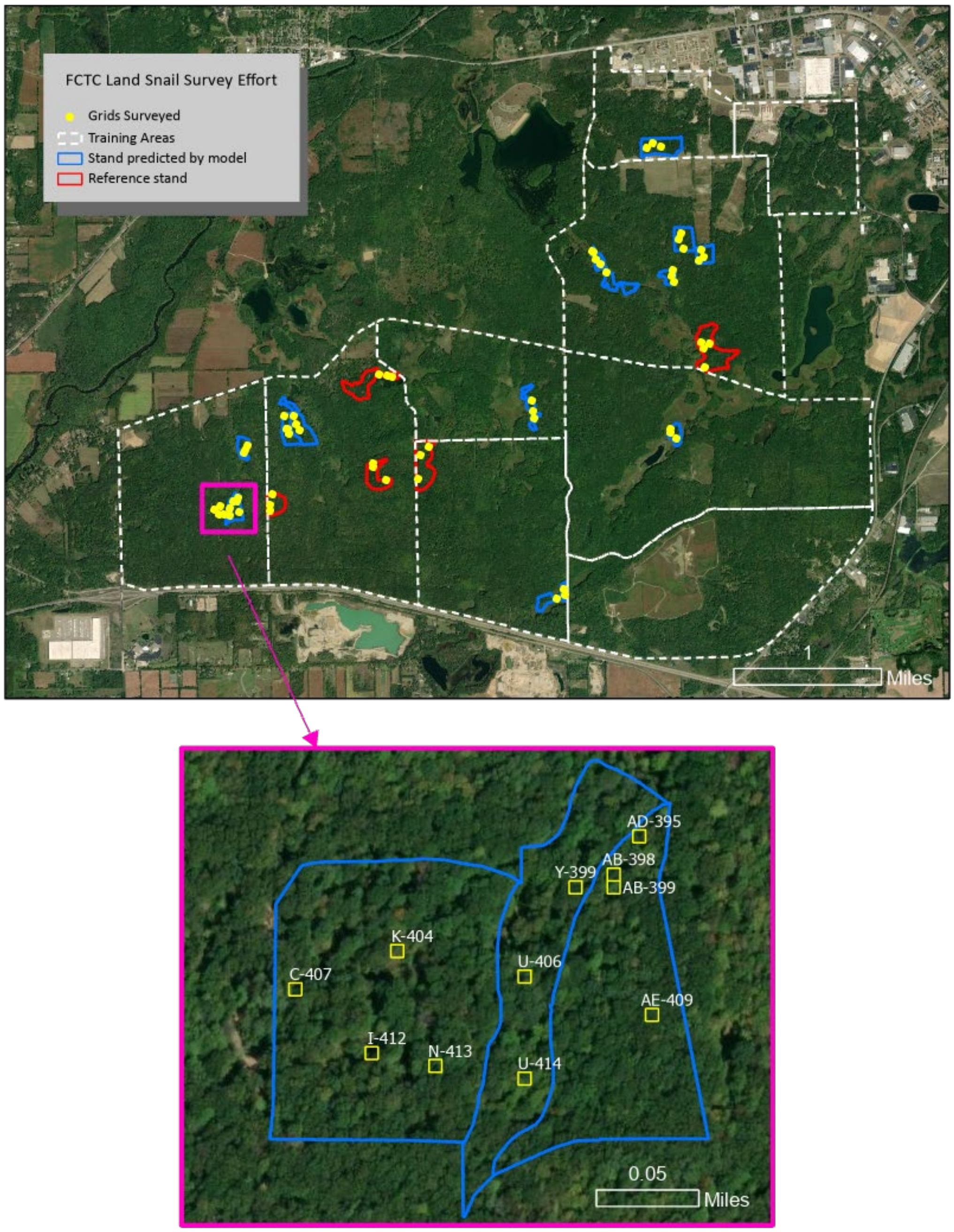


Figure 1. Top: Land snail survey plots (N=59) at Fort Custer Training Center. Bottom: Zoomed in map showing 3 forest stands and locations and IDs of sampled plots.

Analysis

To determine potential relationships between species richness/abundance and microhabitat, a Pearson correlation test in R version 4.2 (R Core Team 2023) was used to test for correlation between land snail species abundance and richness, and landcover data (% cover of downed wood, moss, bare ground, litter cover, and vegetation), as well as EcoScore, of the associated survey plot. Percentage data were normalized using an arcsine transformation (p-critical <0.05).

Snails were collected in vials for identification in the laboratory.

Observed rare species abundance at each survey plot was subsampled and the same correlation analysis was performed using another Pearson correlation test to determine if any measured variables could be used to predict rare snail abundance (p-critical <0.05). Finally, combined snail species abundance and richness across both survey methods was compared using a final series of Pearson correlation tests to determine if any difference was present between mean abundance and richness values for model predicted and reference stands (p-critical <0.05).

Additional analysis on snail data was conducted in the 'vegan' package in R to look at trends across the land snail community and survey areas (Okansen et al. 2022, R Core Team 2023). The first of these analyses was species accumulation across both surveys' methods. Species accumulation curves are often used to determine the likelihood that all present members of a taxonomic group were detected during targeted surveys for that group (Ugland et al. 2003). This analysis would also allow us to determine the survey effort needed to confidently assume all present species of land snail have been observed. A final analysis completed in the 'vegan' package was non-metric multidimensional scaling (NMDS), a form of ordination to evaluate potential relationships between land snail species occurrence and habitat variables. NMDS uses specified variables to place species observed onto a plane with the variables included serving as directional measures of similarity. This allows us to create and observe groupings of species based on these variables to determine trends of similarity and how a change in the given variable may influence that species. NMDS was conducted on all observed snail species using the same ground cover variables, the EcoScore of the plot, and observed snail species diversity as environmental factors.

Figure 2. Four snail species requiring magnification for identification. Left top: ice thorn (*Carychium exile*), left bottom: bottleneck snaggletooth (*Gastrocopta contracta*); Right top: quick gloss (*Zonitoides arboreus*), right bottom: bronze pinecone (*Strobilops aeneus*). Bar is 0.5mm in diameter.

RESULTS

Of the 498 stands mapped within the MiFI Database at FCTC, the model narrowed down the potential survey area for the 26 selected rare species to 90 stands, 14 of which were prioritized for 2021-2022 land snail surveys. Of the 5,487 acres of stands, the model narrowed down the potential survey area for the 26 rare species targets to 863 acres, 211 acres predicted for land snails.

A photo of a land snail found on a piece of decaying woody debris, taken with a clip-on magnifying glass on an iPhone at Fort Custer Training Center.

Land Snail Surveys

We sampled 59 plots in 19 stands and observed 820 snails, including fragments and unidentifiable juveniles. These snails represent 31 confirmed species. Some shells were not identifiable to species because they were fragments, immature, or, in some cases, an identification could not be reached due to uncertain ID characters (e.g., *Vertigo* spp.; Appendix D). Every survey plot except one had at least one snail detected between both methods. Eight survey plots had no snails observed during visual surveys but had snails collected during litter surveys; whereas only three study plots observed snails during visual surveys but had no snails in the litter collection (Table 3).

In 2021 we surveyed 15 plots and observed 205 snails, comprising 15 land snail species and 1 aquatic snail species. The aquatic species, the sharp sprite (*Promenetus exacuous*), is widely distributed in sluggish streams, shallow areas of lakes and rivers, as well as intermittent ponds and mud flats (Baker 1928). This species was collected while sampling a stand (Plot NM-505, EcoScore 4.5) adjacent to the high-quality Longman Road Bogs, so it is likely that this species had made its way up the hill to our upland forested plot by moving, high water, or predator. In 2022 we surveyed 44 plots and collected 615 snails comprising 28 land snail species. Snails of the genus *Vertigo* were collected in both survey years. Due to the difficulty of separating variable vertigo (*Vertigo gouldii*) from the State Threatened delicate vertigo *(V. bollesiana)* some specimens were identified as Vertigo spp. MNFI scientists are currently working with experts of the genus to identify collected individuals to species. This report and the Natural Heritage Database will be edited upon confirmation of these final species identifications.

Average snail species abundance and richness did not differ between reference and predicted stands (Figure 3). The EcoScore of the plots also had no predictive power on snail species richness, abundance, or diversity in either survey method; with the highest abundance and richness being documented at a surveyed plot with one of the lowest EcoScores (Figure 3). Microhabitat environmental variables did not appear to have much influence on species abundance (Figures 4, 5). Regarding rare snail species that have occurrences tracked in the Michigan Natural Heritage Database; Pearson correlation tests results allowed us to infer that higher land snail species richness appeared to correlate with increased counts of *Vertigo* spp. and median striate (*Striatura meridionalis*). Additionally, higher % groundcover of vegetation appeared to correlate with higher counts of median striate.

Through analysis of species accumulation trends, we found that increasing the number of sites that were surveyed in the second year of this project led to a dramatic increase in the number of species detected, for both visual and litter sampling methods. Graphs for each method suggest that survey efforts are approaching an asymptote of species observed (Figure 6). The generated species accumulation curves suggest that additional survey effort would yield additional species but that the asymptote was reasonably close with the survey effort of this study (Figure 6).

A final analysis completed was non-metric multidimensional scaling (NMDS), a form of ordination to evaluate potential relationships between land snail species occurrence and habitat variables. In the case of our analysis, we used habitat composition variables and species diversity within study plots (Figure 7). When looking at combined results of all survey methods, all observed land snail species appeared to form a tight cluster of similarity based on vectors used in our NMDS. The one aquatic snail species observed (*Promenetus exacuous*) was found to be a significant outlier when compared to all land snail species and was removed from the analysis to allow better interpretation of results (Figure 7). The introduced species glossy pillar (*Cochlicopa lubrica*) appears to separate from the majority of native snail species as well with the exception of the striped whitelip (*Webbhelix multilineata*). While all land snails tended to form a tight cluster of similarity along these values there are some suggestions of trends that can be found. Within land snails some species such as striped whitelip and dentate supercoil (*Paravitrea multidentata*) are along opposite sides of the vector for dead wood with the striped whitelip being influenced by the minimal amount of dead wood coverage. Other snails clustered along a grouping of appearing in low diversity stands; for instance, bronze pinecone *(Strobilops aeneus aeneus*) appeared at the lowest end of the vector for plant species diversity. These outliers still appear within a tight cluster, however, so the effects may be minimal or due to chance but additional replicates of surveys would assist in better defining these relationships.

Table 3. Summary of survey results and stand information from Fort Custer Training Center land snail surveys, including summary totals for each stand (2-3 plots/stand). Counts are of entire snails, not fragments; unidentifiable juveniles are included in abundance.

Training Area / Stand	Stand Type	EcoScore	Visual Survey Abundance	Visual Survey Richness	Litter Survey Abundance	Litter Survey Richness	Total Abundance	Total Richness
4/45	Predicted	4	20	4	20	7	38	9
10/30	Predicted	4	10	4	14	6	20	9
7/72	Predicted	4.5	47	6	14	4	59	8
9/69	Predicted	5	17	6	10	4	23	9
3/35	Predicted	4	5	4	23	7	27	8
4/24	Predicted	5	7	3	21	8	24	8
8/36	Predicted	5	9	3	22	4	31	5
9/82	Predicted	4	28	7	16	4	40	10
4/32	Predicted	4	6	4	37	5	39	9
3/55	Predicted	4	20	5	11	4	28	6
9/91	Predicted	4	23	6	11	7	31	9
9/62	Predicted	4	15	3	49	9	54	10
5/63	Predicted	4.5	0	0	8	3	8	3
3/62	Predicted	4	11	6	16	4	24	7
5/2	Reference	2	11	5	27	7	30	8
9/41	Reference	1.5	26	9	43	11	64	15
4/15	Reference	2	23	3	9	6	29	7
4/47	Reference	3	12	4	20	4	30	6
3/46	Reference	4	8	3	18	5	25	7

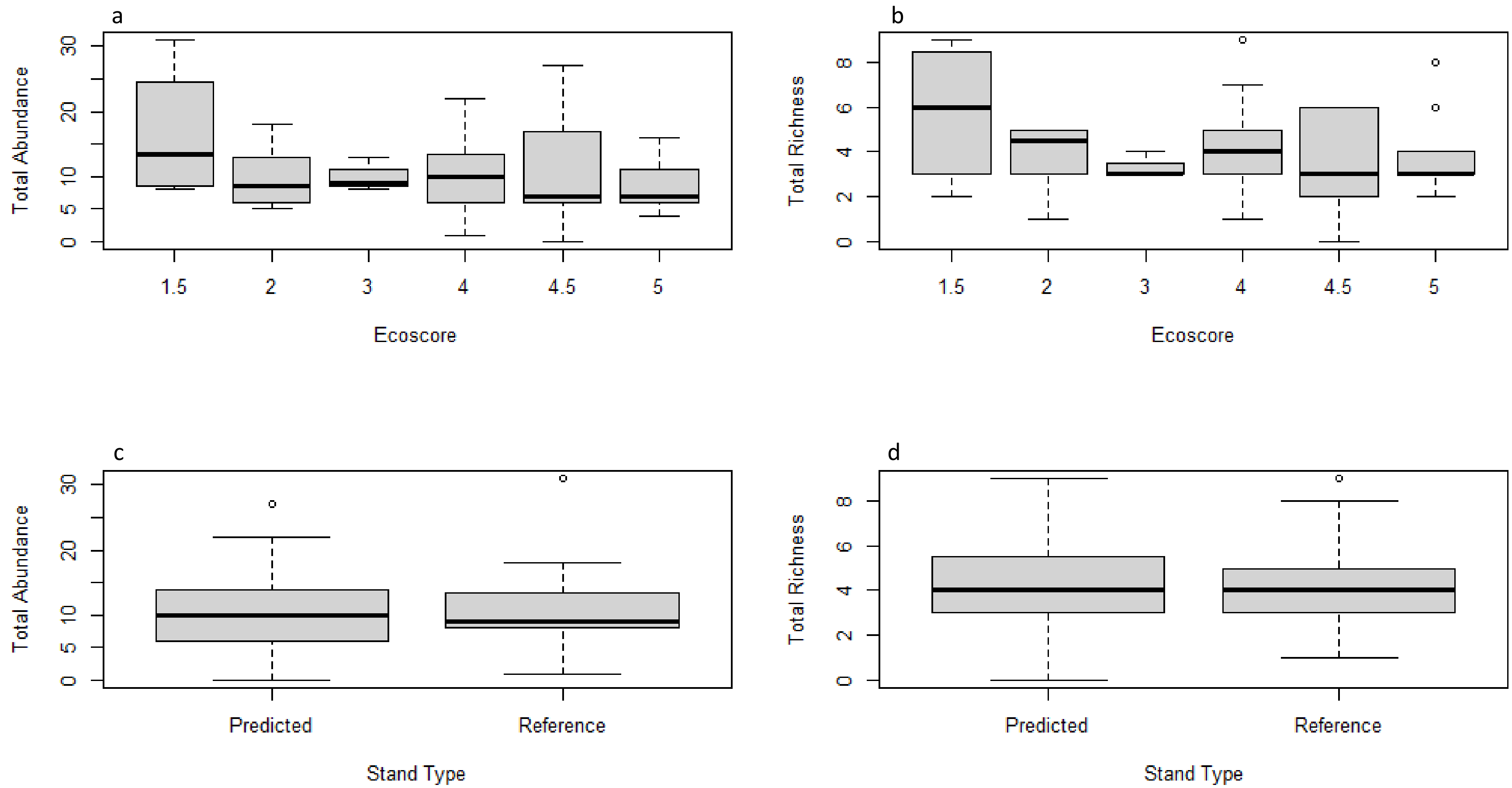


Figure 3. Box plots of the ranges of abundance (a) and richness (b) of land snails between reference stands and stands of varying EcoScores and by the prediction of the MNFI habitat suitability model at FCTC.

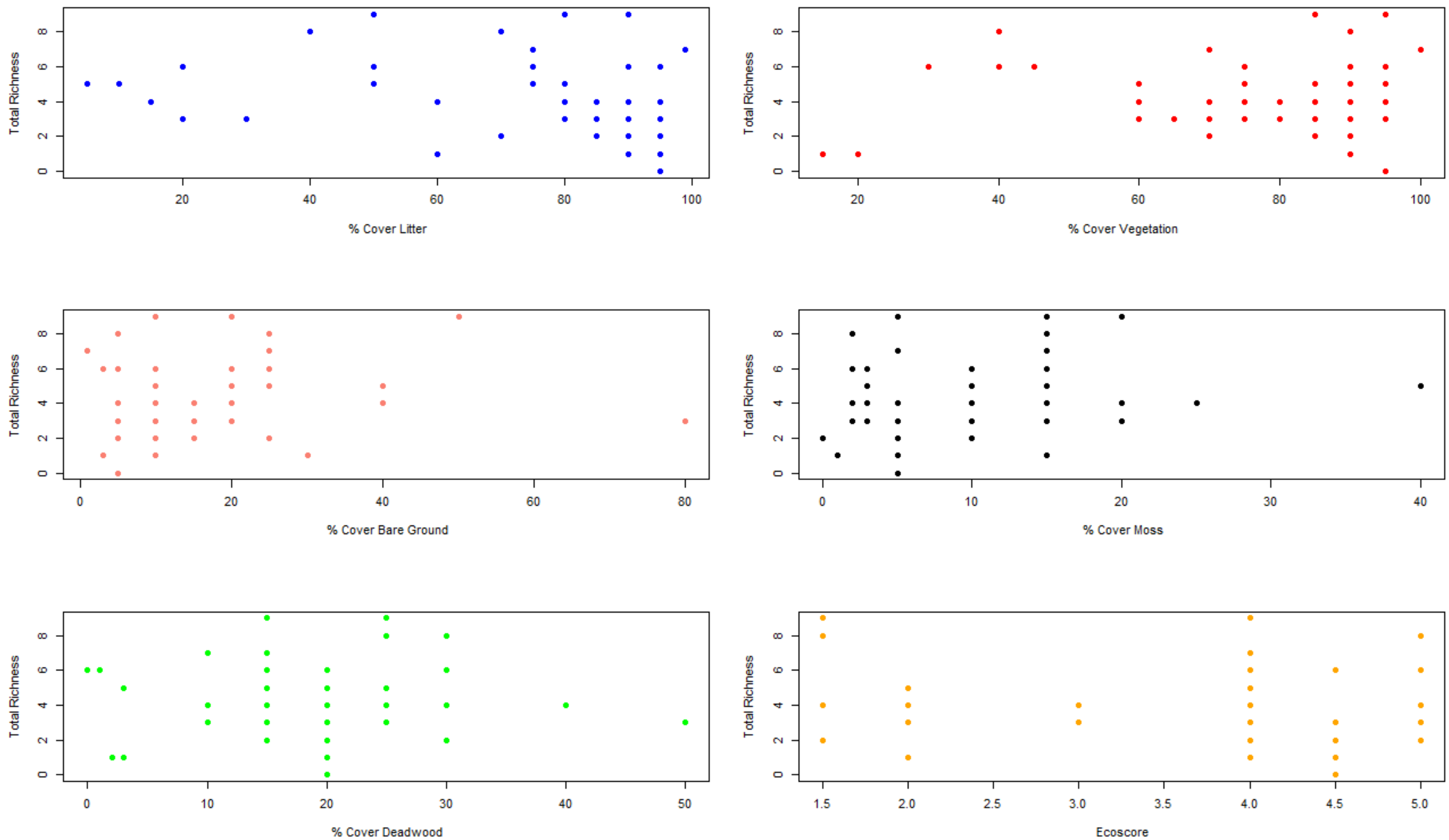


Figure 4. Groundcover variables and EcoScore as relating to land snail species richness at Fort Custer Training Center.

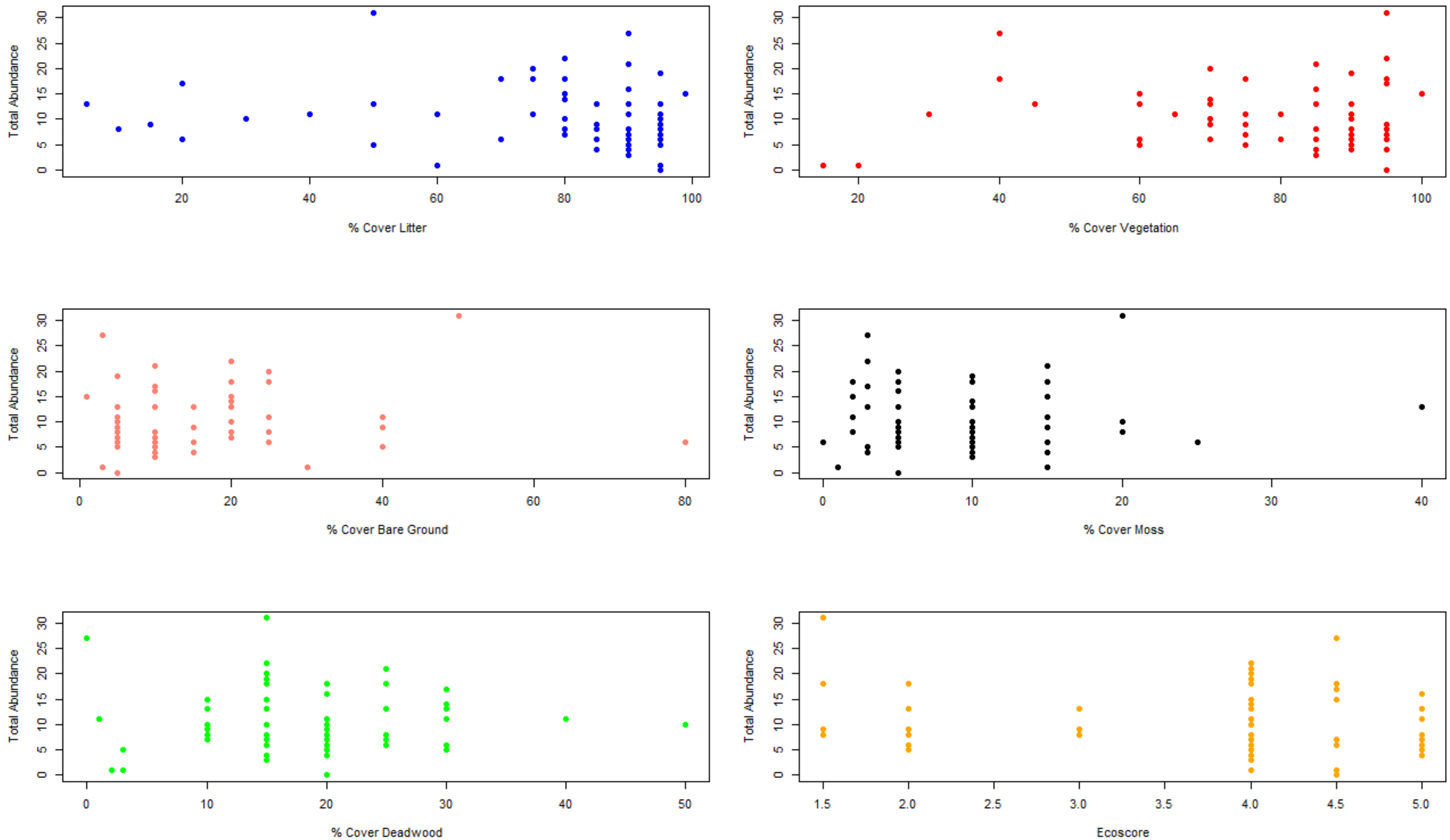


Figure 5. Groundcover variables and EcoScore as relating to land snail species abundance at Fort Custer Training Center.

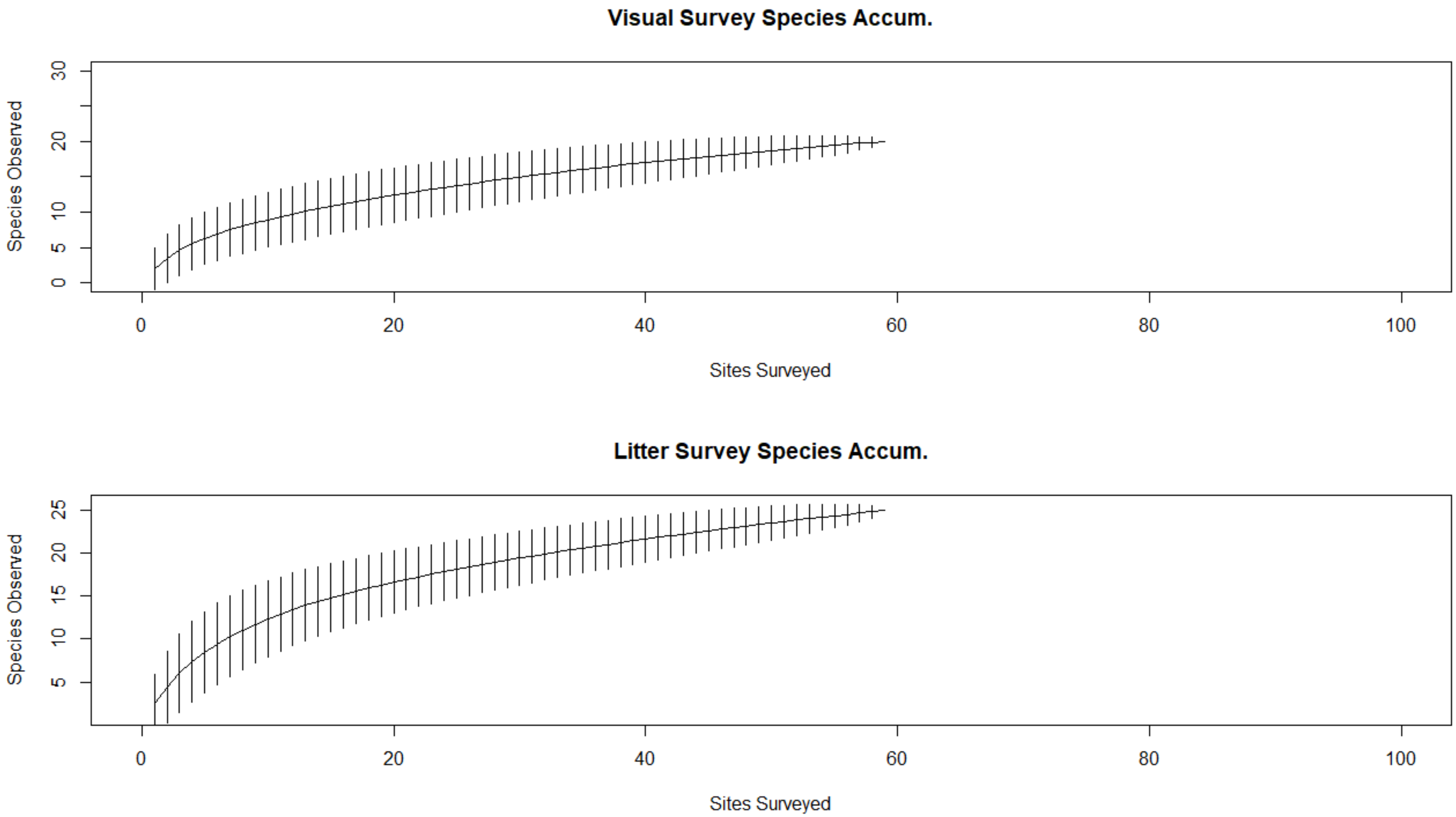


Figure 6. Species accumulation curves of visual and litter surveys for snail species observed at Fort Custer Training Center.

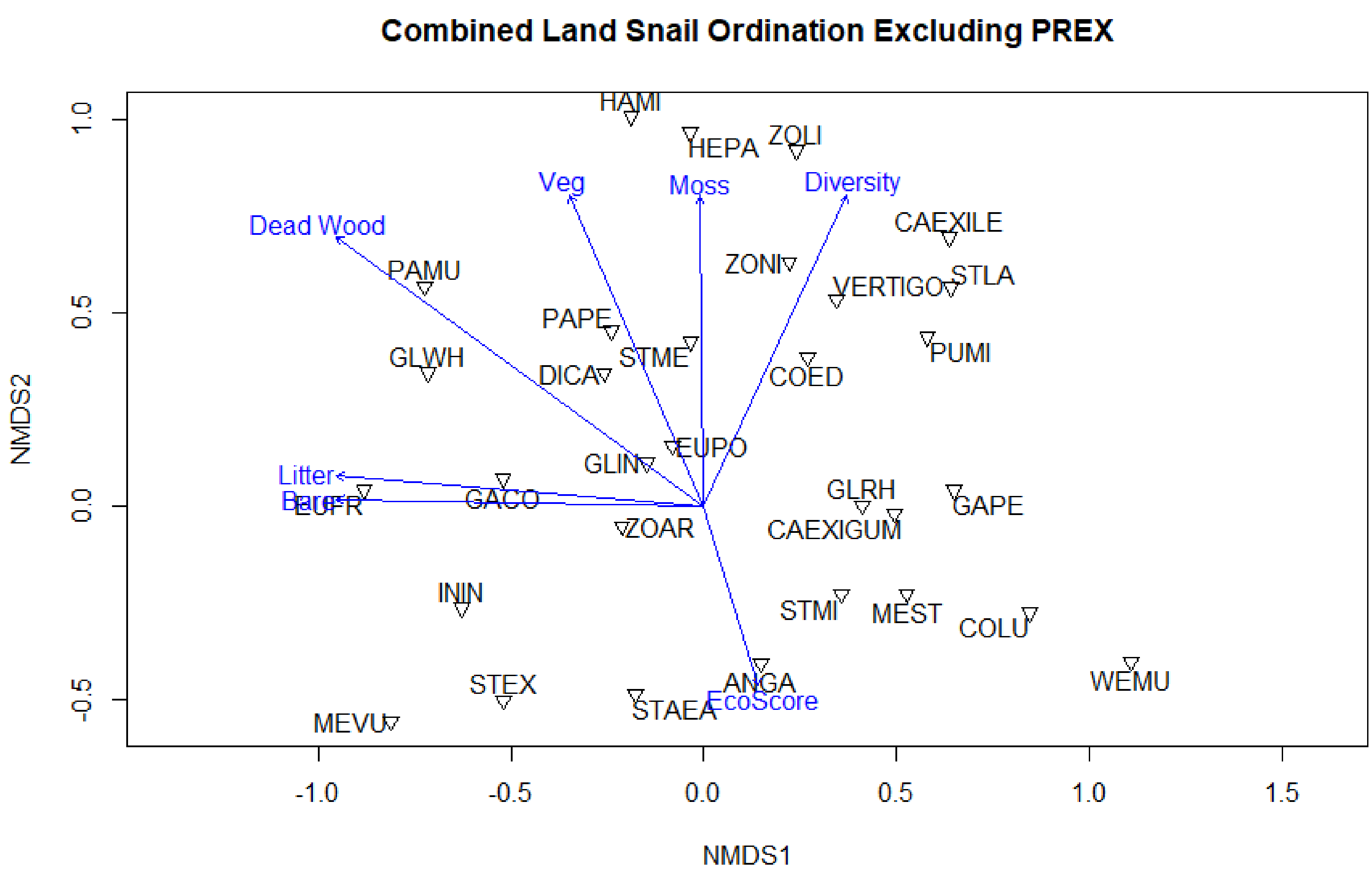


Figure 7. Non-metric multidimensional scaling (NMDS) of all land snail surveys (visual and litter), omitting the single aquatic snail collected (*Promenetus exacuous; PREX*). See Appendix D for species abbreviations.

Rare Species Summary

The Natural Heritage Database maintained by Michigan Natural Features Inventory includes occurrences of 441 plant species, 332 animal species (including 41 land snail species), and 77 natural communities. These data are used to guide conservation and management in Michigan. All records of listed land snail species were added into Michigan's Natural Heritage Database and assigned an Element Occurrence ID (EO ID; Table 4). We documented occurrences of two rare land snails at FCTC: median striate *(Striatura meridionalis,* Special Concern) and proud globelet (*Patera pennsylvanica,* Special Concern, Table 4).

Table 4. Natural Heritage Database summary of rare land snail occurrences at Fort Custer Training Center. Both species listed are Special Concern in Michigan.

Species Name	Common Name	Element Occurrence	Source Features
Striatura meridionalis	Median striate	24848	70375, 73436, 73437
Striatura meridionalis	Median striate	26389	73432, 73434, 73435, 73441, 73442, 73443
Striatura meridionalis	Median striate	26390	73438
Striatura meridionalis	Median striate	26391	73439
Striatura meridionalis	Median striate	26392	73440
Patera pennsylvanica	Proud globelet	26488	74309
Patera pennsylvanica	Proud globelet	26487	74307, 74308

In 2021 we found one occurrence of the median striate, and in 2022 we documented 29 occurrences in 12 plots, this geospatial information has been made available to FCTC Environmental staff through the ArcGIS Online Web App. In communications with MNFI, land snail expert Dr. Nekola suggested that this finding is interesting as it is limited in the upper Midwest to the east shore of Lake Michigan, with its Michigan range basically corresponding to the peach growing areas, and it does not become common until south of the Ohio River (Nekola 2022). This species is found in moist leaf litter in hardwood forests, including wooded hillsides, floodplains, and ravines (Hubricht 1985, Hotopp et al. 2013). Finding several populations of median striate at FCTC helps to inform the distribution of this species throughout Michigan and the Midwest United States where the conservation status of the species is largely unknown (NatureServe 2023). This species appeared to be influenced by groundcover variables, with abundance correlated with increasing vegetation cover. This trend could be used to assist in predicting suitable habitat for median striate for future surveys.

Our records of proud globelet at FCTC represent the first observation of this species in Kalamazoo County, and the first observation not based on historic museum specimens in the Michigan Natural Heritage Database. The proud globelet is a large (15-20 mm) land snail that is a member of the Polygyridae family, and generally occurs on wooded hillsides or in ravines, under leaf litter and stones, but also on grassy roadsides (Hubricht 1985). This snail is found from southwestern Ontario south to Iowa and Missouri and east to Pennsylvania. The proud globelet has also been documented to be declining across its range, with The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listing the species as Endangered and West Virginia ranking the species as critically imperiled (COSEWIC 2015; NatureServe 2023). Recent studies in Ontario at historic sites found no live individuals, but only recently dead (5-15 years old) shells with several possible explanations to explain the decline, including microhabitat changes, contamination, and climate change (COSEWIC 2015). The ecological significance of proud globelet is largely unknown; however, like most other snails and slugs it likely plays important roles in forest ecosystem functioning, specifically by aiding in decomposition, nutrient cycling and soil building processes, providing food and essential nutrients to wildlife, and serving as hosts for parasitic worms (Mason 1970a, 1970b, Jennings and Barkham 1979, South 1980, Churchfield 1984, Frest and Johannes 1995, Martin 2000, Nyffeler and Symondson 2001).

Rare or potentially rare species observed at FCTC. Left Column both photos: Vertigo spp, Right top: Median striate (Striatura meridionalis). Right bottom: Proud globelet (Patera pennsylvanica).

It is possible that we observed the State Threatened delicate vertigo (*Vertigo bollesiana*) at FCTC, however we have not been able to confirm the species identification. Vertigo species can be difficult to identify with the delicate vertigo being nearly identical to the more common variable vertigo (*V. gouldii)* with the key identifier being the size of the depression on a palatal lamella (Nekola 2003). There was no consensus on species ID based on current photos and specimens, despite seeking expert opinion from multiple institutions and comparing FCTC specimens to those in university collections. Vertigo species are relatively understudied across their range; if presence of the delicate vertigo is confirmed at FCTC this would be the first record of the species in the Lower Peninsula of Michigan (MNFI 2023). The MNFI has retained these specimens and continues to seek identification of these specimens.

Example of an immature shell that could not be identified to species, as immature shells lack features necessary for identification.

DISCUSSION

The first goal of this project produced habitat suitability models for rare invertebrates at FCTC, many of which can be used for future survey endeavors. Below, in *Recommendations for future rare species surveys* we provide suggestions for further directions for survey prioritization based on our efforts.

Land snail survey results from this study provide further confirmation that FCTC is an important center for biodiversity in southwest Michigan. The results also establish important baseline data for land snail community richness and abundance. This includes the documentation of rare land snails, which provides FCTC Environmental staff with data to inform land management. Because these snails are relatively sedentary, it is important to manage for and protect them where they occur. Land snails may also be present in additional areas throughout the base that were not surveyed, as we found that high quality natural communities may not be indicative of land snail abundance and richness, possibly because the overall ecological quality of the site (derived from the EcoScore; Appendix A) may not influence land snail community composition. The highest abundance and richness of land snails was found in a reference stand with the lowest EcoScore (1.5) of all stands we surveyed. However, this stand is adjacent to a high quality natural community; with the primary reason for its low EcoScore being a large incursion of black locust (*Robinia pseudoacacia*, Bassett 2023). While the forests of this stand may not be high quality from a natural community perspective, the site likely contained sufficient microhabitat, moisture, litter, and/or groundcover to support snail populations. Our results suggest that high land snail abundance and occurrences of rare species are not correlated with habitat variables such as stand age or the subjective "quality" of forested stands using the EcoScore variable.

We suggest that future land snail research at FCTC include a wider variety of natural community types to continue to document species richness and abundance on the installation. Longer term monitoring of plots in which we documented high abundance and richness may also be used to provide relative abundance and demography information for snails.

Analysis of microhabitat groundcover composition at FCTC remained largely inconclusive as to overall trends of landcover influence on land snail richness and abundance, which reinforces the idea that these low vagility organisms are best protected in areas that they currently occupy. These results are consistent with what previous researchers have documented, as land snails are fairly generalist and will eat, or at least taste, many organic and even inorganic materials that they can crawl to or on (Speiser 2001, Hotopp et al. 2013). In combination with limited dispersal – land snails may move less than 15 m over the course of 3-month period – they may be unlikely to move out of a given microhabitat unless it is highly unsuitable (Baur and Baur 1990). As all study areas at FCTC were natural areas, land snails would likely have little reason to leave the areas as long as they remain relatively undisturbed.

Land snails have been found to exhibit a wide range of habitat preferences, varying with species and region, but their main survival requirements are moisture, food, shelter, and a source of calcium for shell building and physiological processes (Burch and Pearce 1990). Land snail presence may be influenced by microhabitat moisture and topography, but in habitats with suitable structures (e.g., dead wood and rocks) species richness will often remain high even if other habitat variables seem unsuitable (Kemencei et al. 2014). Land snails may also show more habitat preference in more disturbed environments with low remaining natural habitat, though this has only been documented on much finer scales compared to our work (Nandy et al 2021). Disturbed habitat may influence species richness, as certain species such as the glossy pillar (*Cochlicopa lubrica*) are strongly synanthropic and has been found to mostly occur at disturbed sites (Forsyth 2004). In our study this species was documented in stands with lower EcoScores. Other possible biochemical factors may influence snail habitat selection, such as calcium availability (Nandy 2022).

The variable vertigo (Vertigo gouldii) is one of the minute land snail species we observed at Fort Custer Training Center.

NMDS analysis supports these conclusions, as almost all land snail species clustered into close groups of similarity along the ecological gradients we measured. Notable exclusions to these trends include the aquatic snail species sharp sprite (*Promenetus exacuous*), and the glossy pillar. The NMDS clustering of many observed land snail species allows us to further infer that as long as the natural land snail habitat present at FCTC is protected and not disturbed, these species will continue to persist in areas where they currently occur. Some trends observed in NMDS may require more research to fully understand, namely the appearance of a cluster of species near the lowest end of the diversity vector. This may be indicative of species that outcompete other land snail species; or may be individuals that persist in sub-optimal environments. More information on the life history of these species would be necessary to determine the extent of these relationships.

In addition to rare species found at FCTC, we documented several snails that have no current conservation rank in Michigan, but are listed as threatened to critically imperiled in nearby states and provinces (Table 5). The lack of conservation status of this species in Michigan may be due to a lack of data rather than a lack of rarity or need for conservation. For example, the fat hive (*Euconulus polygyratus*) is listed as vulnerable in neighboring Wisconsin and Ontario, and critically imperiled in Kentucky and West Virginia (Table 5; NatureServe 2023). The shagreen snail (*Inflectarius inflectus)* is listed as extirpated in Wisconsin and critically imperiled in Ontario (Table 5; NatureServe 2023). The toothless column (*Columella edentula*) is listed as vulnerable in Ontario (Table 5; NatureServe 2023). More information on the abundance and distribution of these species in Michigan is required to assess the status. The occurrences documented at FCTC in this study serve as an important first step to inform future conservation of these species.

Table 5. Observed land snail species with no conservation rank in Michigan and are listed as threatened to critically imperiled in nearby states and provinces.

Species Name	Common Name	Number snails observed at FCTC	Number plots observed at FCTC
Columella edentula	Toothless column	2	1
Euconulus polygyratus	Fat hive	2	2
Inflectarius inflectus	Shagreen snail	2	1

Recommendations for future rare species surveys

Future studies of land snails at FCTC should continue to monitor known populations of rare land snails to assess the stability and long-term viability of these occurrences. Additionally, more stands should be surveyed with a similar protocol to document more species. For example, a snail study focusing on calcareous communities, such as tamarack swamps and sedge-dominated prairie fens, could detect occurrences of the deep-throat vertigo (*Vertigo nylanderi*, State Endangered) and the tapered vertigo (*V. elatior*, Special Concern). Analyzing these factors could also help to understand land snail microhabitat selection trends and predict other areas at FCTC.

Habitat modelling presented in this study may be applied to other invertebrate species. For example, we identified four moths with potential to be found at FCTC that we recommend for future studies: three-staff underwing (*Catocala amestris,* State Endangered), quiet underwing (*C. dulciola*, Special Concern), Magdalen underwing (*C. illect*a, Special Concern), and the leadplant moth (*Schinia lucens*, State Endangered). The three-staff underwing and the leadplant moth both rely on leadplant (*Amorpha canescens*) as their host, and our model provided one stand where this plant can be found. However, one downfall of the MiFI framework is that the focus is on stand-level attributes where surveyors walk a representative transect through each stand, rather than a comparatively time consuming complete herbaceous inventory; therefore, a suitability model relying on MiFI data alone will likely underestimate the number of stands that contain leadplant. Through communications with MNFI botanists, we believe there are three more sites where leadplant may be found at FCTC (Bassett 2023). The quiet underwing feeds on hawthorns (*Crataegus spp*.), which were documented in one stand but may occur in others. The Magdalen underwing relies on honey locust (*Gleditsia triacanthos*), which is known to be present in four stands. Nocturnal blacklighting surveys during the adult flight period in suitable habitat with a high density of host plants is the best method for detecting these species.

Many snails were found on decaying limbs and branches during visual land snail surveys at Fort Custer Training Center.

Another understudied group of species at FCTC are rare beetles, including the six-banded longhorn beetle (*Dryobius sexnotatus,* State Threatened) and American burying beetle (*Nicrophorus americanus*, possibly State Extirpated, Federally Endangered). To our knowledge, no targeted research for carrion beetles or longhorn/boring beetles has been conducted at FCTC. The American burying beetle has not been observed in Michigan since 1961 but may inhabit a wide range of habitats at FCTC. The same MiFI model we used for this land snail study predicted 14 stands that have potential for the six-banded longhorn beetle, and targeted surveys could help to understand that species distribution as well as other rare and declining beetle species. Recent research suggests that pheromone-baited traps prove effective in capturing rarely encountered species of cerambycid beetles such as the six-banded longhorn beetle, and these protocols could be modified for application at FCTC (Diesel et al. 2017).

Another possibility for future surveys is the tamarack tree cricket (*Oecanthus laricis*, Special Concern), which may be found in one stand at FCTC where its host plant, the tamarack tree (*Larix laricina*), occurs. This rare cricket's range includes FCTC and can be found by sweep netting tamarack trees in August and September.

Recommendations and Threat Mitigation

Land snail communities are among the most sensitive to anthropogenic and other disturbances (Frest and Johanna 1995). As low-vagility organisms that cannot escape rapid alterations to their environment, the "survive where you are" life strategy is necessary for the survival of land snails (Coppolino 2010). Although land snails are equipped with multiple adaptations for survival, some of the greatest threats to snails are anthropogenically induced (Hyman 1967). To protect these ecologically important invertebrates, development and human activity should be minimized in areas where rare species and/or high snail species richness are observed.

Prescribed fire is important for managing natural communities, including dry-mesic southern forests. One study found that wildfires drastically reduced land snail abundance in the short-term, however both species richness and community diversity were promoted in the long-term, given that the time between successive fires was at least five years, after the communities reach equilibrium post-burn (Kiss et al. 2003). Another study confirms that frequent use of fire management appears to represent a significant threat to the health and diversity of North American grassland land snails and suggests a lengthier fire return interval of 15 or more years (Nekola 2002). In addition to providing this length of time between burns, is important to maintain cryptic refuges for land snails during burns. Land snails may drown under water, so activities that would cause flooding at FCTC should be avoided in stands that contain listed species, including excessive beaver flooding.

Most land snails are generalist herbivores, but many also feed on fungus or detritus, and a few snail species are carnivorous, consuming other snails, slugs, and invertebrates in the soil (Burch and Pearce 1990). Undisturbed forests have different succession levels of vegetation and contain fallen logs, which are favorable habitat for snails of all diets to find food and shelter (Coppolino 2010). These sources of habitat should be considered for snail populations at FCTC by allowing leaf cover and native vegetation to persist. If forestry management activities are conducted, it is best that they include leaving some fallen logs in the forest to support snails (Pearce and Örstan 2007). Introduced snail species can become a threat to local land snail populations by competing for microhabitat space and food resources (Robinson 1999). To prevent the introduction of non-native snails at FCTC, care should be taken to properly clean boots, vehicles, and equipment that enter natural areas, including removing mud and vegetation that may contain snail propagules.

Climate-related threats to land snails include temperature extremes, drought (Schweizer et al. 2019), and loss of snow cover in temperate regions (Nicolai and Ansart 2017). Unfavorable climatic conditions can have severe consequences for land snails including thermal and desiccation deaths which, even in areas of moderate climate, have been known to cause mass morality events (McQuaid et al. 1979). Further complicating matters is that, although not without exception, land snails have limited dispersal ability to modify range extent and may not be able to disperse quickly enough to follow the migration of suitable habitat due to climate change (Nicolai and Ansart 2017). The continual monitoring and consideration of land snails in management activities at FCTC will allow the installment to maintain its diverse land snail community.

LITERATURE CITED

Badra, P.J. 2023. Surveys for Watercress Snail *(Fontigens nickliniana*) in and around Fort Custer Training Center. Michigan Natural Features Inventory Report Number 2023-03, Lansing, MI.

Baker, F. 1928. Freshwater Mollusca of Wisconsin, Part I, Gastropoda. Bulletin Wisconsin Geological and Natural History Survey. Vol 70. University of Wisconsin Press, Madison.

Barker, G.M. 2001. The biology of terrestrial mollusks. Oxon, UK: CABI Publishing. 558 pp.

Bassett, T.J., A.A. Cole-Wick, P. Badra, D.L. Cuthrell, H.D. Enander, P.J. Higman, Y. Lee, C. Ross, and L.M. Rowe. 2022. Natural Features Inventory of Fort Custer Training Center. Michigan Natural Features Inventory Report Number 2022-09, Lansing, MI. 91 pp. + xi, Appendices

Bassett, T.J. 2023. Michigan Natural Features Inventory. Personal Communication.

Baur, A. and B. Baur. 1990. Are Road Barriers to Dispersal in the Land Snail *Arianta arbustorum?* Canadian Journal of Zoology, 68. 4pp.

Burch, J.B. and T.A. Pearce. 1990. Chapter 9: Terrestrial gastropods. pp 201-309 in D. L. Dindal (ed.) Soil Biology Guide. John Wiley and Sons, New York. 1349pp.

Churchfield, S. 1984. Dietary separation in three species of shrew inhabiting water-cress beds. J. Journal of Zoology. 204(2). 228pp.

Cohen, J.G., M.A. Kost, B.S. Slaughter, D.A. Albert, J.M. Lincoln, A.P. Kortenhoven, C.M. Wilton, H.D. Enander, and K.M. Korroch. 2020. Michigan Natural Community Classification [web application]. Michigan Natural Features Inventory, Michigan State University Extension, Lansing, Michigan.

Cole-Wick, A.A. 2018. Evaluation of Fort Custer Training Center for Presence of the Federally Endangered Karner Blue Butterfly. Kalamazoo Nature Center.

Cole-Wick, A.A., L. Rowe, P. Badra, T. Bassett, Y. Lee, C. Ross, J. Paskus, and M. Monfils. 2020. Natural Features Inventory of Saginaw Chippewa Indian Tribe Lands. Michigan Natural Features Inventory, Report Number 2020-13, Lansing, MI, USA.

Cole-Wick, A.A., C. Brennan, C.M. Wilton. 2022. Prairie Vole (*Microtus ochrogaster*) Population Monitoring at Fort Custer Training Center: 2020-2021. Michigan Natural Features Inventory Report Number 2022-01, Lansing, MI.

Coppolino, M.L. 2010. Strategies for Collecting Land Snails and Their Impact on Conservation Planning. American Malacological Bulletin, 28(2). 7pp.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2015. COSEWIC Assessment and Status Report on the Proud Globelet in Canada. 52pp.

Cuthrell, D. 2022. Michigan Natural Features Inventory. Personal Communication.

Derosier, A.L., S.K. Hanshue, K.E. Wehrly, J.K. Farkas, and M.J. Nichols. 2015. Michigan's Wildlife Action Plan. Michigan Department of Natural Resources, Lansing, MI. available online at: http://www.michigan.gov/dnrwildlifeaction

Eckhardt, S.G., L.M. Rowe, and C.N. Ross. 2022. A Survey of Monarch Butterflies and Bumble Bees at Fort Custer Training Center. Michigan Natural Features Inventory, Report No. 2022-43, Lansing, MI.

Forsyth, R. 2004. Land Snails of British Columbia. Royal BC Museum, 2004. 188pp.

Frest, T.J. and E.J. Johannes. 1995 An Annotated Checklist of Idaho Land and Freshwater Mollusks. Journal of the Idaho Academy of Science, 36(2). 51pp.

Hotopp, K.P., T.A. Pearce, J.C. Nekola, J. Slapcinsky, D.C. Dourson, M. Winslow, G. Kimber, and B. Watson. 2013. Land Snails and Slugs of the Mid-Atlantic and Northeastern United States. Carnegie Museum of Natural History, Pittsburgh, PA, USA.

Hubricht, L. 1985. The Distributions of the Native Land Mollusks of the Eastern United States. Field Museum of Natural History.

Hyman, L.H. 1967. The Invertebrates. Vol. VI. Mollusca I: Aplacophora, Polyplacophora, Monoplacophora, Gastropoda the Coelomate Bilateria. McGraw Hill, 1967. 792pp.

INRMP [Integrated Natural Resource Management Plan]. 2020. Fort Custer Training Center Integrated Natural Resources Management Plan Updated April 2020. Michigan Department of Military and Veterans Affairs Construction and Facilities Management Office Environmental Division 3423 North Martin Luther King Jr Boulevard Lansing, Michigan 48906.

Jennings, T.J. and J.P. Barkham. 1979. Litter Decomposition By Slugs in Mixed Deciduous Woodland. Ecography, 2. 8pp.

Kemencei, Z., R. Farkas, B. Páll-Gergely, F. Vilisics, A. Nagy, E. Hornung, P. Sólymos. 2014. Microhabitat Associations of Land Snails in Forested Dolinas: Implications for Coarse Filter Conservation. Community Ecology, 15(2). 6pp.

Kiss, L., F. Magnin and F. Torre. 2004. The Role of Landscape History and Persistent Biogeographical Patterns in Shaping the Responses of Mediterranean Land Snail Communities to Recent Fire Disturbances. Journal of Biogeography 31. 12pp.

Lydeard, C., R. H. Cowie, W. F. Ponder, A. E. Bogan, P. Bouchet, S. A. Clark, K. S. Cummings, T. J. Frest, O. Gargominy, D. G. Herbert, R. Hershler, K. E. Perez, B. Roth, M. Seddon, E. E. Strong, and F. G. Thompson. 2004. The global decline of nonmarine mollusks. Bioscience, 54. 9pp.

Martin, S.M. 2000. Terrestrial Snails and Slugs (Mollusca: Gastropoda) of Maine. Northeastern Naturalist, 7(1). 55pp.

Mason, C.F. 1970a. Food, Feeding Rates and Assimilation in Woodland Snails. Oecologia, 4. 27pp.

Mason, C.F. 1970b. Snail Populations, Beech Litter Production, and the Role of Snails in Litter Decomposition. Oecologia, 5. 24pp.

McQuiad, C.D., G.M. Branch, P.G.H. Frost. 1970. Aestivation Behavior and Thermal Relations of the Pulmonate Theba pisana in a Semi-arid Environment. Journal of Thermal Biology, 4(1). 8pp.

Michigan Natural Features Inventory [MNFI]K. 2023. Michigan's Special Animals: Endangered, Threatened, Special Concern, and Probably Extirpated. Available online at: https://mnfi.anr.msu.edu/species/animals

NatureServe. 2023. NatureServe Network Biodiversity Location Data accessed through NatureServe Explorer [web application]. NatureServe, Arlington, Virginia. Available https://explorer.natureserve.org/. (Accessed: March 15, 2023).

Nandy, G., H. Barman, S. Pramanik, S. Banerjee, G. Aditya, G. 2022. Land Snail Assemblages and Microhabitat Preferences in the Urban Areas of Kolkata, India. Journal of Urban Ecology. 13pp.

Nekola, J.C. 2002. Effects of fire management on the richness and abundance of central North American grassland land snail faunas. Animal Biodiversity and Conservation 25:2

Nekola, J.C. 2003. Key to the terrestrial gastropod genera of Wisconsin and nearby states.

Nekola, J.C. 2023. Masaryk University. Personal Communication.

Nicolai, A., and A. Ansart. 2017. Conservation at a Slow Pace: Terrestrial Gastropods Facing Fast-Changing Climate. Conservation Physiology, 5:1.

Nyffeler, M., Symondson, W.O.C. 2001. Spiders and harvestmen as gastropod predators. Ecological Entomology, 26. 11pp.

O'Brien, M.F., D.S. O'Brien, J.A. Craves. 2017. Cordulegaster erronea Hagen in Selys (Tiger Spiketail) Rediscovered in Michigan (Odonata: Cordulegastridae). The Great Lakes Entomologist, 50:1-2.

Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M, De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlinn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J (2022). vegan: Community Ecology Package. R package version 2.6-4, <https://CRAN.R-project.org/package=vegan>.

Overton, J. M., G. M. Barker, and R. Price. 2009. Estimating and Conserving Patterns of Invertebrate Diversity: A Test Case of New Zealand Land Snails. Diversity and Distributions, 15. 10pp.

Pearce, T.A. and A. Örstan. 2006. Terrestrial Gastropoda. In C. F. Sturm, T. A. Pearce, and A. Valdés, eds., The Mollusks: A Guide to Their Study, Collection, and Preservation. American Malacological Society. Pp. 261-285.

Robinson, D.G. 1999. Alien Invasions: The Effects of the Global Economy on Non-marine Gastropod Introductions Into the United States. Bioscience, 50. 12pp.

Rowley, M.A., E.S. Loker, J.F. Pagels, R.J. Montali. 1987. Terrestrial Gastropod Hosts of Parelaphostrongylus tenuis at the National Zoological Park's Conservation and Research Center, Virginia. The Journal of Parasitology, 73:6. 6pp.

R Core Team. 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Schweizer M., R. Triebskorn, H-R Köhler. 2019. Snails in the Sun: Strategies of Terrestrial Gastropods to Cope With Hot and Dry Conditions. Ecology and Evolution, 9. 20pp.

South, A. 1980. A Technique for the Assessment of Predation by Birds and Mammals on the Slug Deroceras reticulatum (Müller) (Pulmonata: Limacidae). Journal of Conchology, 30. 5 pp.

Speiser, B. 2001. Chapter 6: Food and Feeding Behavior. (pp. 259- 288 in: The Biology of Terrestrial Mollusks), G.M. Barker, Ed. CABI, New York, USA. 558pp.

K.I. Ugland, J.S. Gray, K.E. Ellingsen. 2003. The species–accumulation curve and estimation of species richness. The Journal of Animal Ecology. 72:5. 888-897

United States Fish and Wildlife Service (USFWS). 2023. Environmental Conservation Online System. Accessed 3/2/2023. Available online at https://ecos.fws.gov/ecp0/reports/ad-hoc-species-report.

APPENDICES

Appendix A**.** Descriptions of EcoScores assigned to natural communities during stand mapping.

1 = Very heavily modified by past human activity. Essentially destroyed from a natural plant community perspective. Most native vegetation or community assemblage is gone. Invasive species likely dominant. Examples: Weedy tree groves on spoil areas, former farm fields now containing non-native cover, and marshes with rampant non-native Phragmites.

2 = Heavily modified by past human activity. Native vegetation or community assemblage is reduced to an altered state but still recognizable as having once been some type of a natural community (the original type of community may not be obvious). Examples: early seral scrub areas grown after clearcutting, "ponds" formed after meadows are impounded, marshes with growing populations of cattail, or old upland fields with a mix of native and non-native grassland species.

3 = Moderately to heavily altered by past human activity. Native vegetation or community assemblage is altered but somewhat recognizable as a type of a natural community (the original type of community may still be present, but it is not a very high-quality example). Examples: early to mid-seral forest areas grown after logging 10 to 60 years prior, wet meadows with some hydrologic impact, prior ditching, or some invasive species, marshes with low species diversity and scattered purple loosestrife, or old upland fields with several prairie species mixed with non-native grassland species.

4 = Lightly to moderately altered by past human activity. Native vegetation or community assemblage is apparently altered but quickly recognizable as a type of a natural community (the original nature of the natural community type is not entirely certain due to a history of factors like fire suppression or past tree removal, but the site has a fairly natural level of plant diversity and is more or less sustainable). Examples: maturing native forest areas grown after logging 60 years-or-more prior, or native forest recovering from selective tree removal, or wet meadows with increasing brush but covered almost entirely by native species.

5 = Unaltered to lightly altered by past human activity. Native vegetation or community assemblage may be a bit altered but is clearly a natural community (the original nature of the natural community type could be debated due to a history of factors like fire suppression or past selective tree removal, but the site has a natural level of plant diversity, many conservative species, and if correctly managed is sustainable). Examples: Mature native forest with no indications of human modification, mature native forest which may have been selectively logged 50 or more years prior, mature native forest which may have been heavily logged in the 1800s, wet meadows with little brush and covered by native species, or marshes with diverse native species composition.

Appendix B. List of rare invertebrate species considered for models because of their potential to occur at Fort Custer Training Center based on current or historical range, and reasoning for eliminating from 2021-2022 rare species surveys.

Species name	Common name	Reason for eliminating
Alasmidonta marginata	Elktoe	Recent study (Bassett et al. 2022)
Alasmidonta viridis	Slippershell	Recent study (Bassett et al. 2022)
Basilodes pepita	Gold moth	Host plant not detected at FCTC (Bassett et al. 2022)
Bombus affinis	Rusty-patched bumble bee	Recent study (Eckhardt et al 2022)
Bombus auricomus	Black and gold bumble bee	Recent study (Eckhardt et al 2022)
Bombus pensylvanicus	American bumble bee	Recent study (Eckhardt et al 2022)
Bombus terricola	Yellow banded bumble bee	Recent study (Eckhardt et al 2022)
Calephelis mutica	Swamp metalmark	Not detected at FCTC
Cambarus robustus	Big water crayfish	Recent study (Badra 2023)
Cincinnatia cincinnatiensis	Campeloma spire snail	Recent study (Badra 2023)
Cordulegaster erronea	Tiger spiketail	Recent study (O'Brien 2017)
Cyclonaias tuberculata	Purple wartyback	Recent study (Bassett et al. 2022)
Epioblasma triquetra	Snuffbox	Recent study (Bassett et al. 2022)
Euphyes dukesi	Dukes' skipper	Recent study (Cole-Wick 2018)
Faxonius immunis	Calico crayfish	Recent study (Badra 2023)
Flexamia reflexa	Leafhopper	Recent study (Bassett et al. 2022)
Fontigens nickliniana	Watercress snail	Recent study (Badra 2023)
Lampsilis fasciola	Wavyrayed lampmussel	Recent study (Bassett et al. 2022)
Lasmigona compressa	Creek heelsplitter	Recent study (Bassett et al. 2022)
Lasmigona costata	Flutedshell	Recent study (Bassett et al. 2022)
Ligumia nasuta	Eastern pondmussel	Recent study (Bassett et al. 2022)
Ligumia recta	Black sandshell	Recent study (Badra 2022)
Lycaeides melissa samuelis	Karner blue	Recent study (Cole-Wick 2018)
Neonympha mitchellii	Mitchell's satyr	Not detected at FCTC
Oarisma poweshiek	Poweshiek skipperling	Not detected at FCTC (Cuthrell 2022)
Obliquaria reflexa	Threehorn wartyback	Recent study (Bassett et al. 2022)
Papaipema beeriana	Blazing star borer	Recent study (Bassett et al. 2022)
Papaipema cerina	Golden borer	Recent study (Bassett et al. 2022)
Papaipema maritima	Maritime sunflower borer	Recent study (Bassett et al. 2022)
Papaipema sciata	Culvers root borer	Sufficient host plant population not detected (Bassett et al. 2022)
Papaipema silphii	Silphium borer moth	Sufficient host plant population not detected (Bassett et al. 2022)
Papaipema speciosissima	Regal fern borer	Recent study (Bassett et al. 2022)

Pleurobema clava	Clubshell	Recent study (Bassett et al. 2022)
Pleurobema sintoxia	Round pigtoe	Recent study (Bassett et al. 2022)
Pomatiopsis cincinnatiensis	Brown walker	Recent study (Badra 2023)
Potamilus alatus	Pink heelsplitter	Recent study (Bassett et al. 2022)
Ptychobranchus fasciolaris	Kidney shell	Recent study (Bassett et al. 2022)
Pygarctia spraguei	Sprague's tiger moth	Recent study (Bassett et al. 2022)
Sphaerium fabale	River fingernail clam	Recent study (Badra 2023)
Stenelmis douglasensis	Douglas Stenelmis riffle beetle	Recent study (Badra 2023)
Toxolasma lividus	Purple lilliput	Recent study (Bassett et al. 2022)
Toxolasma parvum	Lilliput	Recent study (Bassett et al. 2022)
Truncilla donaciformis	Fawnsfoot	Recent study (Bassett et al. 2022)
Truncilla truncata	Deertoe	Recent study (Bassett et al. 2022)
Utterbackia imbecillis	Paper pondshell	Recent study (Bassett et al. 2022)
Venustaconcha ellipsiformis	Ellipse	Recent study (Bassett et al. 2022)
Villosa fabalis	Rayed bean	Recent study (Bassett et al. 2022)
Villosa iris	Rainbow	Recent study (Bassett et al. 2022)

Appendix C1. Summary of land snail survey plots with name, whether the plot was predicted by the model or reference, and percent cover of litter, moss, vegetation, and bare ground.

Plot	Predicted/ Reference	% Cover Litter	% Cover Moss	% Cover Vegetation	% Cover Bare	% Cover Dead Wood	Year Sampled
AB-399	Reference	80	10	70	20	20	2021
AD-395	Reference	95	1	20	3	3	2021
AF-409	Reference	80	10	70	20	30	2022
AJ-342	Predicted	80	5	70	20	15	2021
AJ-345	Predicted	90	2	30	5	1	2021
AM-336	Predicted	90	5	75	10	15	2022
BM-402	Reference	95	10	95	5	10	2022
BN-391	Reference	95	3	85	5	15	2022
BN-407	Reference	90	10	85	10	20	2022
CB-305	Predicted	95	15	65	5	20	2022
CE-320	Predicted	90	15	85	10	25	2021
CF-326	Predicted	95	5	80	5	20	2022
CM-306	Predicted	85	15	90	15	20	2022
CO-314	Predicted	85	25	85	15	30	2022
CS-321	Predicted	50	10	45	20	15	2021
D-407	Predicted	95	20	70	5	50	2022
FU-357	Predicted	75	5	70	25	15	2022
FV-362	Predicted	85	5	60	15	30	2022
GB-260	Reference	80	10	95	20	15	2022
GH-375	Predicted	20	5	60	80	15	2022
GK-262	Reference	90	5	90	10	20	2022
GP-263	Reference	95	5	75	5	5	2021
HR-374	Reference	5	40	90	10	25	2022
HT-347	Reference	10	10	85	25	15	2022
ID-339	Reference	15	15	75	40	20	2022
K-403	Predicted	85	10	85	15	20	2022
MK-290	Predicted	20	3	95	10	30	2022
MM-301	Predicted	80	2	60	20	15	2022
MN-308	Predicted	90	3	40	3	0	2021
N-413	Predicted	90	10	70	15	10	2021
NM-505	Predicted	60	15	15	30	2	2021
NU-494	Predicted	95	5	95	5	20	2022
NU-501	Predicted	80	5	95	20	10	2022

OZ-126	Predicted	90	3	95	10	15	2021
PD-136	Predicted	30	5	90	5	10	2022
PI-140	Predicted	80	3	95	20	15	2022
PO-148	Predicted	80	5	95	20	15	2022
RG-15	Predicted	90	10	85	10	15	2022
RI-9	Predicted	75	15	75	25	20	2022
RV-12	Predicted	90	10	90	10	15	2022
SF-324	Predicted	95	10	90	5	15	2022
SG-320	Predicted	95	20	90	5	15	2022
SH-154	Predicted	70	0	70	25	30	2021
SI-147	Predicted	75	15	75	25	20	2022
SL-160	Predicted	90	10	95	10	25	2022
SM-330	Predicted	90	5	85	10	20	2022
SP-113	Predicted	90	10	90	5	20	2021
SS-106	Predicted	40	15	90	5	30	2022
SU-123	Predicted	90	10	90	10	30	2022
T-414	Predicted	60	2	80	40	40	2022
TK-135	Predicted	99	15	100	1	10	2022
TN-123	Predicted	95	10	90	5	15	2022
TN-225	Reference	70	2	40	25	25	2021
TO-132	Predicted	95	15	95	5	25	2022
TR-232	Reference	85	5	95	5	10	2022
TR-252	Reference	50	20	95	50	15	2022
TX-226	Reference	85	5	70	15	20	2022
U-406	Predicted	50	3	60	40	3	2021
Y-399	Predicted	80	2	85	20	25	2022

Appendix C2. Summary of percent (%) of groundcover variables as: minimum value-maximum value (mean value).

	Litter %	Moss %	Vegetation %	Bare Ground %	Dead Wood %
Reference	5-95 (71)	3-40 (11)	15-95 (77)	5-80 (18)	3-30(18)
Predicted	20-99 (79)	0-20 (8)	20-100 (78)	1-50 (14)	0-50 (19)
All Stands	5-99 (76)	0-40 (9)	15-100 (78)	1-80 (15)	0-50 (19)

Appendix D. List of land snail species observed during surveys at Fort Custer Training Center, including total number observed, and the number of plots in which each species was observed.

Scientific Name	Common Name	Name Abbreviation	Number Snails Observed	Number of Plots Observed
Hawaiia minuscula	Minute gem	HAMI	4	4
Carychium exile	Ice thorn	CAEXILE	24	8
Carychium exiguum	Obese thorn	CAEXIGUM	1	1
Cochlicopa lubrica	Glossy pillar	COLU	4	1
Columella edentula	Toothless column	COED	2	1
Discus catskillensis	Angular disc	DICA	5	4
Anguispira alternata	Flamed tigersnail	ANGA	36	23
Mesodon thyroidus	White-lip globe	MEST	43	22
Mesomphix vulgaris	Copper button	MEVU	1	1
Heliodiscus parallelus	Compound coil	HEPA	1	1
Euconulus polygyratus	Fat hive	EUPO	2	2
Punctum minutissimum	Small spot	PUMI	53	16
Gastrocopta contracta	Bottleneck snaggletooth	GACO	12	10
Euchemotrema fraternum	Upland pillsnail	EUFR	5	5
Gastrocopta pentodon	Comb snaggletooth	GAPE	1	1
Inflectaruis inflectus	Shagreen snail	ININ	2	1
Vertigo spp.*	Vertigo species	VERTIGOS	7	5
Vertigo gouldii	Variable vertigo	VERTIGO	9	4
Strobilops aeneus aeneus	Bronze pinecone	STAEA	122	32
Strobilops labyrinthiucus	Maze pinecone	STLA	5	1
Glyphyalinia indentata	Carved glyph	GLIN	31	17
Glyphyalinia rhoadsi	Sculpted glyph	GLHR	2	2
Glyphyalinia wheatleyi	Bright glyph	GLWH	1	1
Paravitrea multidentata	Dentate supercoil	PAMU	2	2
Patera pennsylvanica	Proud globelet (SC)	PAPE	3	3
Zonitoides nitidus	Black gloss	ZONI	3	3
Zonitoides limatulus	Dull gloss	ZOLI	1	1
Zonitoides arboreus	Quick gloss	ZOAR	209	46
Striatura meridionalis	Median striate (SC)	STME	29	12
Striatura milium	Fine-ribbed striate	STMI	13	6
Webbhelix multilineata	Striped whitelip	WEMU	1	1
Striatura exigua	Ribbed striate	STEX	1	1
*Promenetus exacuous***	Pulmonate freshwater snail	PREX	1	1
Shell fragments			113	31
Immature shells			71	40
Total number of snails observed			820	

*Potentially multiple species, pending final ID's

**Aquatic snail observed during upland land snail surveys survey