ELK RESPONSES TO RECREATIONAL USE AND HABITAT POTENTIAL IN MICHIGAN

By

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ABSTRACT

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The growing use of public lands for nature-based recreation has prompted a demand for research evaluating recreational use and its direct and indirect effects on wildlife populations and their habitat. Although a growing body of research has reported numerous negative effects that recreational use can have on wildlife resources, recent research has demonstrated that suitable habitat may mitigate the effects of human-wildlife interactions. In Michigan, the Pigeon River Country (PRC) and Atlanta (ASF) State Forests serve as the core range of Michigan's elk (*Cervus elaphus nelsoni*) herd. The PRC is a Special Management Unit that limits certain trail-based recreation types (e.g., equestrian use, mountain biking) to designated trails and prohibits some motorized vehicles (e.g., ORVs). Our primary goals were to examine the interactions among elk space-use and resource selection patterns, habitat suitability and potential, and summer trail-based recreation on public lands in the Michigan elk range. For our first objective, we developed habitat suitability index (HSI) and habitat potential models for elk within the Michigan elk range. Our HSI models indicated areas of high habitat suitability and potential for winter thermal cover, winter food, and spring food throughout the elk range. For our second objective, we quantified and compared the intensities and group sizes of common summer trail-based recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) at different temporal scales (i.e., year, month, day, hour) in the PRC and ASF. Recreation was monitored using trail cameras and we captured 11,412 recreation events during 263,664 hours of monitoring in the PRC, and 5,034 events during 266,184 hours in the ASF from May–October, 2016–2018. Greater recreational intensity was detected for all recreation types in both regions during September, weekends, and mid-day (11:00–16:59). The most frequently detected types of recreation were equestrian use (58.8% of events) in the PRC and ORV use (51.8% of events) in the ASF. Our third objective was to evaluate and compare space-use and resource selection patterns for Michigan elk in response to habitat suitability and the intensity of summer equestrian use, hiking, mountain biking, and ORV use at different temporal periods. Global positioning system (GPS) collars were placed on 27 cow and 26 bull elk from 2016–2018. Dynamic Brownian bridge movement models were used to quantify elk space-use patterns, and elk resource selection was modeled at landscape- and home range-scales. Elk home range sizes in May were 1.3–2.0 times greater ($P < 0.05$) than in June–September. Weekends accounted for 36% of the greatest daily elk movement distances. Elk demonstrated changes in the proportional use of cover types within home ranges during peak periods of recreational intensity. For our fourth objective, we evaluated the behavioral responses of elk to experimental recreational events. During September 2018, we monitored 69 equestrian use and 3 mountain biking events using handheld GPS receivers. We evaluated elk responses to encounters with recreation events that occurred within 2 times the average documented flight distance (60 m) for elk in Michigan. We recorded 4 encounters with the same cow elk during our events, and found no responses or changes in habitat use from encounters with recreation events. Our results highlight the need to consider the varying effects of different types of recreation on wildlife populations and the amount and quality of habitat components that may mitigate negative effects of interactions between wildlife and recreational users. Achieving a balance of interactions among wildlife, wildlife habitat, and recreational users is essential for ensuring long-term sustainability of wildlife populations, habitat, and recreational opportunities on public lands.

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PREFACE

This dissertation has been organized into a General Introduction, Study Objectives, Study Area Description, 4 chapters that focus on our 4 primary study objectives, and 5 appendices. The formatting of this dissertation follows the formatting guidelines for manuscripts submitted to the *Journal of Wildlife Management*. Chapter 1 was submitted to the *Wildlife Society Bulletin* on 20–October, 2019, accepted on 9–June, 2020, and published on 18–February, 2021. The co-authors for Chapter 1 were Henry Campa III, Alexandra B. Locher, Scott R. Winterstein, and Dean E. Beyer Jr. Chapter 2 was submitted to the *Journal of Outdoor Recreation and Tourism* on 16–September, 2020, and a revision that was submitted on 28–February, 2021 is in review. The co-authors for Chapter 2 were Henry Campa III, Scott R. Winterstein, Charles M. Nelson, and Dean E. Beyer Jr. Chapter 3 was submitted to the *Journal of Wildlife Management* on 6–July, 2021 and is in review. The co-authors for Chapter 3 were Henry Campa III, Jeffrey W. Doser, Scott R. Winterstein, and Dean E. Beyer Jr. Chapter 4 is being modified for submission to the *Journal of Human-Wildlife Interactions* in fall 2021. The co-authors for Chapter 4 were Henry Campa III and Dean E. Beyer Jr. Appendix A provides elk collaring and capture data during our study. Appendix B provides a history of elk collar deployments, elk mortalities, collar failures, and collar retrievals. Appendix C provides a detailed summary of experimental recreation events from Chapter 4. Appendix D contains metadata describing the organization and storage locations of all data associated with this project. Appendix E contains a description of outreach experience and a list of presentations given to numerous committees and at professional conferences.

GENERAL INTRODUCTION

Trail-based recreation (e.g., equestrian use, mountain biking, ORV use) has increased on public lands within the Michigan elk range over the last 50 years with noticeable growth in visitor numbers and interest in summer trail-based recreational opportunities (e.g., equestrian use, mountain biking, ORV use; MDNR 2007, MDNR 2012). Although Michigan provides 32,375 km^2 of public lands for recreation, the presence of a visible elk (*Cervus elaphus nelsoni*) herd in the Pigeon River Country State Forest (PRC) and part of the adjoining Atlanta State Forest (ASF), makes these areas an attractive destination (MDNR 2018, Hunt 2019). In the last 10 years, increased reports of elk causing agricultural depredation outside of their core range has raised concerns among natural resource managers over the potential impacts of recreational activities on elk movements and behaviors (B. Mastenbrook, MDNR, personal communications). Consequently, natural resources managers have hypothesized that elk may be selecting areas with less recreational activity. Long-term effects of repeated interactions between wildlife and recreational users, such as avoidance of frequently used areas, create challenges for managers attempting to provide wildlife habitat components. Wildlife avoidance of areas used by recreational users can lead to indirect habitat degradation and has been observed in large herbivores such as red deer (*Cervus elaphus*), mountain caribou (*Rangifer tarandus caribou*), and elk (Sibbald et al. 2011, Lesmerises et al. 2018, Wisdom et al. 2018). However, other research has demonstrated that providing suitable habitat may mitigate the negative effects of human-wildlife interactions on wildlife populations (Coppes et al. 2018). To determine the effects of trail-based recreation and habitat suitability and potential on the elk population in northern Michigan, the MDNR and Michigan State University partnered to conduct research examining the interactions among elk, their habitat, and summer trail-based recreational activity.

OBJECTIVES

The objectives of this study were focused on providing natural resources managers with an understanding of the potential effects of interactions among the elk population, their habitat, and summer trail-based recreational users in the Michigan elk range. The objectives were to:

1) Quantify and compare current elk habitat suitability and habitat potential for public and private lands in the Michigan elk range.

2) Quantify and compare the number, relative intensity, frequency, and geographic scope of summer trail-based recreational users (i.e., equestrian users, hikers, mountain bikers, off-road vehicle users) between the Pigeon River Country State Forest (with restricted recreational activities) and portions of the Atlanta State Forest (with limited recreation restrictions) within the Michigan elk range.

3) Quantify and compare elk space-use and habitat selection patterns in response to habitat suitability and the intensity of summer trail-based recreation types (i.e., equestrian use, hiking, mountain biking, off-road vehicle use) at different temporal periods for the Pigeon River Country State Forest and portions of the Atlanta State Forest within the Michigan elk range.

4) Quantify and compare the fine scale responses of GPS-collared elk to experimental equestrian use and mountain biking events within the Pigeon River Country State Forest and portions of the Atlanta State Forest within the Michigan elk range.

STUDY AREA DESCRIPTION

Our study area was the 122,000 ha (66,500 ha of public lands, 55,500 ha of private lands) MDNR defined elk range and surrounding public and private lands within Cheboygan, Montmorency, Otsego, and Presque Isle counties in the northern portion of the lower peninsula of Michigan (Figure 1.1). The region has a humid continental climate with a mean annual temperature of 5.6° C and a mean annual precipitation of 77.9 cm (Michigan Weather Service 1974, NOAA 2016). Temperature extremes can reach 34.4° C in summers and –28.8° C in winters, with a mean snowfall of 198.6 cm (NOAA 2016).

The topography consists of moderately sloped ground moraines and outwash plains in the south connecting to steep moraine ridges among outwash plains in the north (Albert 1995). The southern ground moraines are dominated by drumlin fields that are typically <20 m in elevation, 0.2–0.4 km in width, and 1.6 km in length, separated by poorly drained outwash plains. Steep moraine ridges in the north are surrounded by broad well-drained outwash plains and narrow poorly drained outwash channels, and are characterized by elevation changes of >60 m in distances <1.6 km and are among the steepest in the lower peninsula of Michigan (Albert 1995). Elevation in the study area ranges from 181–335 m in the south to 274–396 m in the north. The Pigeon and Black Rivers originate and drain within the elk range and are prominent within the study area. Soil types range from dry sandy soils with low fertility in outwash plains to sandy loam soils with medium–high fertility in till plains and moraines (USDA 2019).

Vegetation types within the study area vary depending on soil types, drainage, fertility, exposure, and land management practices. Prior to the 1940’s, extensive logging, repeated burning, and scattered attempts at farming further influenced the formation of numerous vegetation types within the study area (Moran 1973, MDNR 2007). Vegetation types within the elk range have been classified into 6 physiographic distributions, namely morainic uplands, steep morainic slopes, outwash plains – morainic ecotones, sandy outwash plains, riverbanks and bottomlands, and coniferous swamps (Spiegel et al. 1963, Moran 1973). Morainic uplands primarily support northern hardwood forest types dominated by sugar maple (*Acer saccharum*), basswood (*Tilia americana*), hemlock (*Tsuga canadensis*), red maple (*A. rubrum*), and beech (*Fagus grandifolia*; Albert 1995). Steep morainic slopes are characterized by aspen (*Populus* spp.) with red maple occurring at the base of slopes and pine (*Pinus* spp.)-hardwood mixtures occurring at mid–high elevations (Albert 1995). Outwash plains – morainic ecotones are considered transitional zones that are often dominated by red maple, white birch (*Betula papyrifera*), and aspen (Moran 1973). Sandy outwash plains primarily support jack pine (*Pinus banksiana*), grasses (*Poaceae* spp.), and forbs with interspersions of cherry (*Prunus* spp.), willow (*Salix* spp.), and juneberry (*Amelanchier Canadensis*; Albert 1995). Riverbanks and bottomland areas support lowland hardwoods and alluvial silt plain sites with common species such as ash (*Fraxinus* spp.), grey alder (*Alnus incana*), dogwood (*Cornus* spp.), and willow (Moran 1973). Coniferous swamps are dominated by northern white-cedar (*Thuja occidentalis*), balsam fir (*Abies balsamea*), black spruce (*Picea mariana*), and balsam poplar (*Populus balsamifera*; Albert 1995). Open areas occur throughout the study area as maintained wildlife openings, natural grasslands (i.e., typically part of barren or savannah communities), and old field grasslands (MDNR 2008).

Land use within our study area is influenced by accessibility to public lands for recreation, production of timber products, and occurrence of agricultural crops and hunt clubs on private lands. The study area is bordered by Federal and state highways with Interstate 75 to its west, Michigan Route 68 to its north, Michigan Route 33 to its east, and Michigan Route 32 to its south. Despite the absence of federal or state highways within the study area, county and seasonal MDNR forest roads occur throughout the Pigeon River Country (PRC) and Atlanta (ASF) State Forests. According to the MDNR Resource Assessment Unit, 88% of the PRC is within 0.8 km of a road (S. Whitcomb, MDNR, personal communication). Approximately 16.2% of private lands within the elk range are club lands (i.e., Black River Ranch [35.5 km^2] and Canada Creek Ranch [54.6 km^2]) that offer hunting, fishing, and outdoor reaction opportunities (Black River Ranch 2019, Canada Creek Ranch 2019). Primary types of public and private land recreation include camping, hunting, fishing, mushroom hunting, berry picking, equestrian use, and mountain biking (MDNR 2007, MDNR 2012).

Public lands within the Michigan elk range included the PRC (45,840 ha) and portions of the ASF (16,800 ha) and Gaylord State Forest Management Units of the Mackinaw State Forest (Figure 1.1). The PRC and portions of the ASF inside of the elk range are considered the core of the elk range. Although both are state forests balancing multiple management objectives for sustainability of forest and wildlife resources and recreational opportunities, the PRC has been designated as a Special Management Unit since 1972 to safeguard its unique variety of undeveloped land cover types and natural resources from overuse and development (MDNR 2007). Notably, the PRC's Concept of Management (COM) describes its specific objectives and guidelines for managing elk and other fish and wildlife species and their habitat, forest and mineral resources, and for providing recreational opportunities (MDNR 2007).

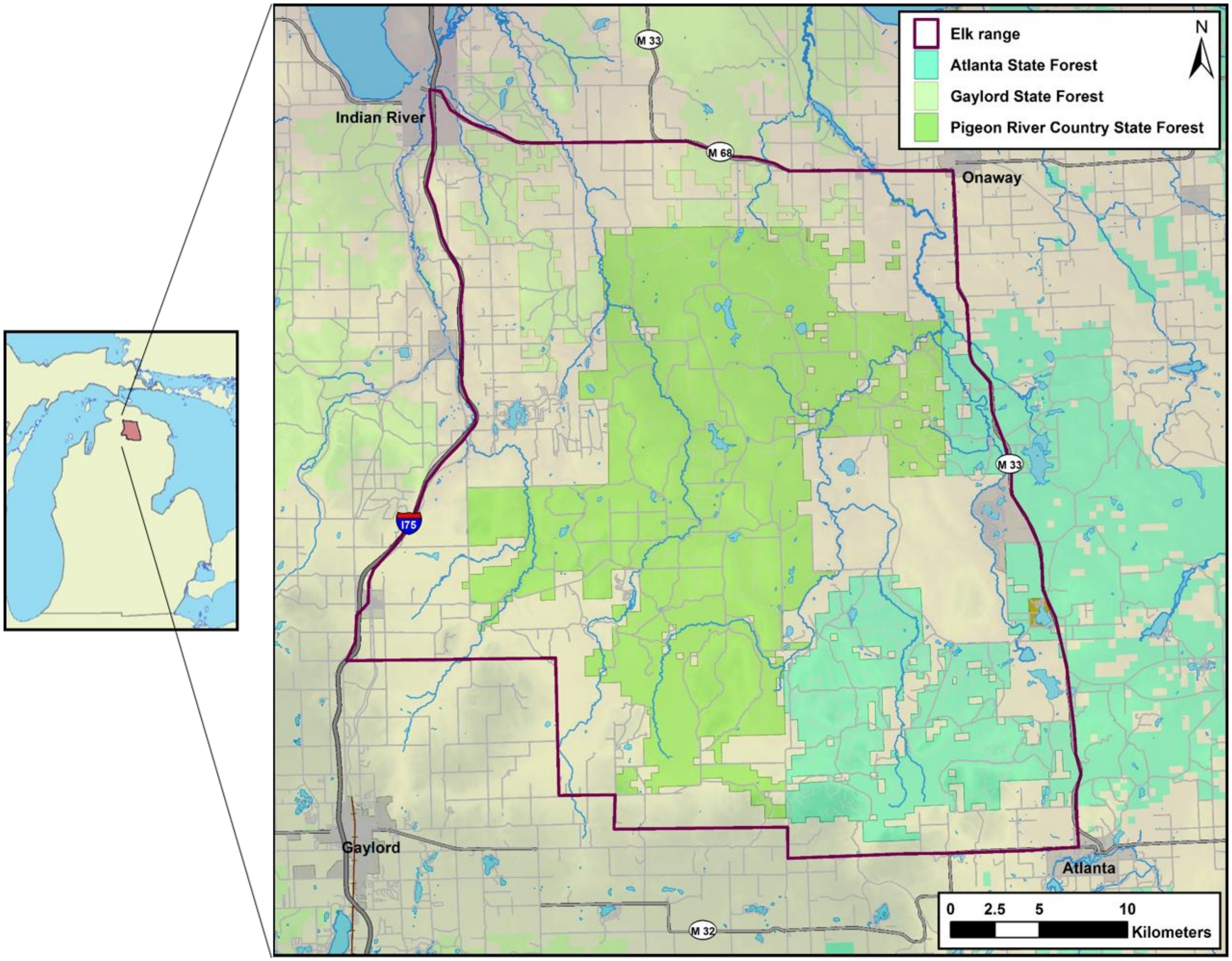


Figure 1.1. Location of the 1,220 km^2 Michigan Department of Natural Resources (MDNR) designated elk range and study area in the northern lower peninsula of Michigan. The Pigeon River Country State Forest (458.4 km^2) and a portion of the Atlanta State Forest (168 km^2) are considered the core of the Michigan elk range.

Elk Herd and Habitat Management

The first objective of the COM is to "manage the elk population and elk habitat so the Pigeon River Country State Forest remains the nucleus of Michigan's elk herd" (MDNR 2007:14). The elk herd has persisted in the region since the introduction of 7 Rocky Mountain elk in 1918 (MDNR 2007). The creation of the Michigan Elk Management Plan by the MDNR (1975) established elk as a priority species and outlined management objectives. The 1984 Elk Management Plan designated the elk range, set a population objective of 600–800 elk, established recreational hunting as the primary method of population management, and recognized the importance of elk viewing opportunities (MDNR 1984). The 2012 Elk Management Plan revised the population objective to 500–900 elk (MDNR 2012). Elk hunts have occurred annually since 1984, and since 2006 the MDNR evaluates herd size using a sightability model (MDNR 2012, Walsh 2007, Walsh et al. 2009). The estimated elk population has remained relatively stable (800–1,400) since 1984, and from 2006–2019 the mean population estimate was 1,065 (SD = 217.4; MDNR 2012, S. Adams, MDNR, personal communication).

Elk habitat is managed on public lands and based on goals defined by the Michigan Elk Management Plan and the PRC's COM (MDNR 2007, MDNR 2012). Beyer (1987) identified the primary life requisites for elk in Michigan as spring food, winter food, and winter thermal cover and thus the management of cover types supporting these requisites is essential for sustaining the population. The goals for forest management include: 1) maintaining 6–7% of the range as grass and upland brush; 2) managing aspen for no net loss, with a goal of aspen representing 27% of the range; 3) maintaining mast production by oak and beech (*Fagus grandifolia*), and increasing production if possible; and 4) sustaining mixed pine (*Pinus* spp.) stands by promoting natural regeneration of coniferous and deciduous species. The goals for openings include maintaining an even distribution of managed (i.e., planted, mowed, burned) openings of at least 400 ha throughout the elk range. The PRC's COM has guidelines for even-aged management that retains <8% of stems or <0.93 m^2 of basal area to be no greater than approximately 16 ha, while the ASF has no size restrictions on even-aged management (MDNR 2007). For private lands, the MDNR communicates options and assists with improving elk habitat if desirable by landowners (MDNR 2012).

Management of Recreational Use

The PRC has regulations for recreational use that restricts specific types of trail-based recreation to a greater extent than the ASF and other state forests in Michigan (MDNR 2016, MDNR 2018a). For example, equestrian users and mountain bikers may only use designated trails and forest roads in the PRC, while being permitted anywhere within the ASF (MDNR 2016, M. Fry, M. Monroe, MDNR, personal communication). Off-road vehicle use is prohibited in the PRC, however, permitted on designated trails and forest roads in the ASF (MDNR 2016, MDNR 2018b). Despite the PRC's unique recreational regulations, the forest offers a greater quantity and variety of recreation-based amenities (e.g., designated campgrounds and trails) than the ASF (Williamson et al. in review). Furthermore, the PRC is arguably more publicized and accessible due to its history as the center of the elk range and close proximity to nearby Interstate-75 and population centers (Williamson et al. in review).

CHAPTER 1: APPLICATIONS OF INTEGRATING ELK HABITAT SUITABILITY AND HABITAT POTENTIAL MODELS

INTRODUCTION

Understanding wildlife-habitat relationships is fundamental for wildlife managers attempting to develop habitat management strategies and predict population responses. Survival and reproductive success of species are, in part, dependent on the amount, condition, and spatial arrangement of habitat components (Van Horne and Wiens 2015). Therefore, it is vital for managers to understand the ecosystem processes that influence the presence and distribution of a species and identify areas that may or may not be suitable for a species' life requisites. Using a habitat-based perspective to examine the suitability of a landscape to support a population is a common approach for predicting the spatial distribution of species (Hirzel and Le Lay 2008). Habitat Suitability Index (HSI) models allow wildlife managers to assess the availability and quality of habitat for a species and continue to be one of the most widespread management tools used by government agencies (Brooks 1997, Latif et al. 2015). Habitat Suitability Index models often rely on expert knowledge to define relevant habitat attributes to describe species' life requisites, and managers often use data from existing vegetation conditions or land-cover databases to identify those attributes (Leblond et al. 2014). Van Horne and Wiens (1991:3) suggested HSIs be viewed as "quantitative expressions of our best working understanding of the relations between easily measured environmental variables and habitat quality for a species." While HSI models can provide spatial information about the quality and distribution of habitat that is available, they are typically limited to current conditions and do not provide predictions of future variations in quality, distribution, or availability of habitat (Thuiller and Münkemüller 2010).

For wildlife managers to make effective habitat management decisions, it is useful to have information about the potential of areas to remain or become wildlife habitat for given species. Wildlife habitat is not static, and the dynamic relationship between wildlife and their habitat is a direct result of the processes by which landscapes and their associated vegetation types change over time (Cushman and McGarigal 2007, Felix et al. 2007b). Therefore, natural resources agencies attempting to model and manage populations should consider the arrangement of species-specific habitat attributes and how they affect wildlife populations across space and time.

Previous research has focused on using “habitat types” (Daubenmire 1966) for predicting changes in vegetation types through time and quantifying habitat potential (e.g., Felix et al. 2004, Felix et al. 2007a, Windmuller-Campione et al. 2015). Felix (2004:796) defined “habitat potential” as “the capability of an area being or becoming habitat based on biological and geological characteristics.” Areas with the same ecological characteristics (e.g., soil characteristics, landforms, climate) and successional trajectories are defined as habitat types (Daubenmire 1966). Delineating habitat types and their boundaries allows managers to identify ecologically similar land units where key information (i.e., measurements) can be extrapolated to all areas of the same type (Kotar 1986). Additionally, identifying habitat types allows managers to quantify habitat potential through the assignment of suitability values (SV) to successional stages based on their ability to provide habitat components for wildlife. Understanding temporal variations in habitat suitability through forest succession can provide insights on effects of landscape changes on wildlife and their habitat, and how wildlife habitat may respond to land-use decisions.

Consideration of current and future habitat availability and quality offers wildlife managers insights on management strategies to maintain or provide additional habitat for species of interest. For example, since the elimination of the eastern subspecies of elk (*Cervus elaphus canadensis*) from Midwestern and eastern North America in the late 1800's, wildlife managers have attempted to manage populations of introduced Rocky Mountain elk (*Cervus elaphus nelsoni*) with varying results (Witmer 1990, O'Gara and Dundas 2002, Keller et al. 2015). Approximately 40% of elk restoration efforts have failed in eastern North America within 5–94 years (Popp et al. 2014). Notably, the most common explanation for elk restoration failure was lack of appropriate habitat quality and/or quantity (Witmer 1990, Popp et al. 2014). Witmer (1990) suggested the use of habitat suitability models or other methods to evaluate elk habitat in areas where restorations are being proposed to increase likelihood of success. While some regions examined potential restoration sites or herd expansion of current elk ranges (Van Deelen 1997, Telesco et al. 2007, Gilbert et al 2010), only current habitat availability and quality was considered. Investigation of current habitat suitability and habitat potential in areas where managers are attempting to establish new or maintain existing populations could provide insights on the spatiotemporal dynamics of habitat availability and quality and likely increase probability of successful restoration efforts and management plans. For example, a habitat potential model can be used to identify habitat types that support aspen and hardwood-dominated vegetation types (i.e., areas of high habitat suitability for elk winter and spring food) as potential restoration sites or focus areas for maintaining or providing additional habitat for elk. Subsequently, an elk habitat suitability model can be used to identify sites that are currently in low suitability within those habitat types as focus areas for elk habitat management efforts.

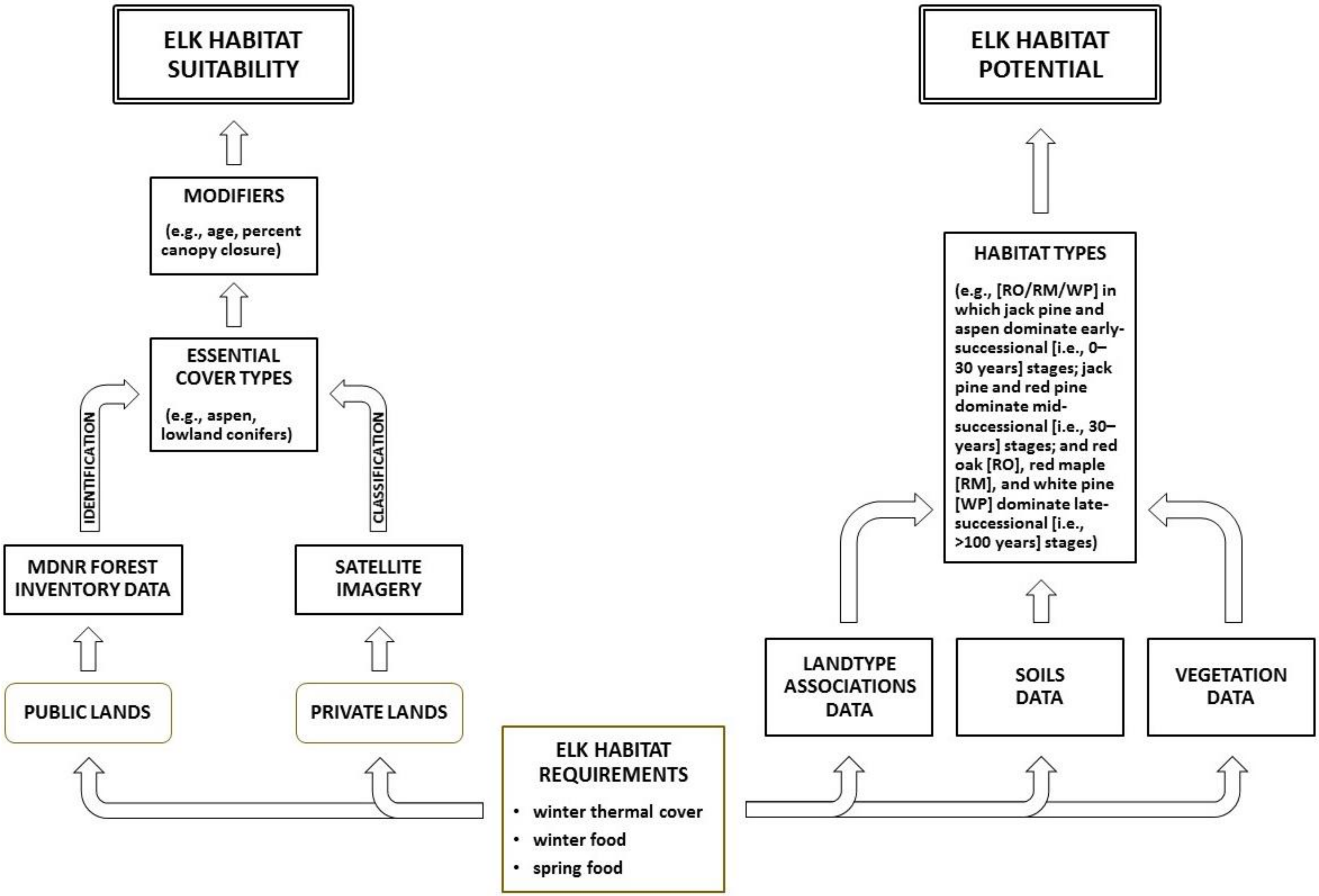
We integrated HSI and habitat potential models for elk in Michigan to identify the spatial and temporal dynamics of their habitat so that results could guide current and future habitat management. In Michigan, one of the primary goals of the Michigan Department of Natural

Resources (MDNR) Elk Management Plan is to "manage for a sustainable elk population in balance with the habitat" (MDNR 2012: 21). Since its conception, Michigan's elk management plan has outlined strategies to manage forests, openings, and private lands to maintain and improve habitat for elk (MDNR 1975, MDNR 1984, MDNR 2012).

Beyer (1987) identified 3 potential habitat limiting factors for elk in Michigan, namely winter thermal cover (WTC), winter food (WF), and spring food (SF). Using these limiting factors, Beyer (1987) developed an HSI model to evaluate the quality of elk habitat throughout the year. Natural resources managers can assess habitat quality to inform management decisions within the elk range. However, determining existing vegetation conditions through land-cover databases or field examination only provides an index of current conditions, requiring managers to make assumptions about potential vegetation and successional dynamics of different habitat types (Felix et al. 2004, Thuiller and Münkemüller 2010). Using models to examine habitat suitability and potential can provide managers with insights on the spatiotemporal dynamics of wildlife habitat for any species of interest with known habitat requirements in a region. Our objective was to demonstrate how the development and integration of elk habitat suitability and habitat potential models can identify desirable landscapes for elk conservation and habitat management and planning.

METHODS

To demonstrate the application of integrating habitat models for wildlife habitat management, we created a set of models (Elk Habitat Suitability – Public Lands, Elk Habitat Suitability – Private Lands, Elk Habitat Potential) to quantify elk habitat suitability and habitat potential for state-owned (hereafter public) and private lands within the MDNR designated elk range (Scheme 1.1). Each model used a framework for quantifying habitat suitability or habitat potential values based on elk habitat requirements (i.e., WTC, WF, SF) and supporting cover types (e.g., aspen, cedar) determined by Beyer (1987) for Rocky Mountain elk in Michigan. Winter thermal cover is provided by cedar and other lowland conifer swamps in Michigan and allows elk to maintain homeothermy during severe winter conditions (Moran 1973, Beyer 1985). Winter food is vital during harsh weather conditions, and is considered as browse (e.g., aspen) that is available to elk above snow cover (Beyer 1987). Spring food is critical for elk to recover any loss of physical condition during winter and generally considered to be high nutritional quality forage made available following or during snow melt (Beyer 1987). While all 3 of these habitat requirements for elk in Michigan occur in winter and spring, availability of food and cover are most critical during these seasons and habitat suitability ratings are assumed to relate directly to quality of habitat throughout the year.



Scheme 1.1. Schematic of model components and processes used to develop habitat suitability and habitat potential models for public and private lands within the elk range in northeastern lower Michigan.

Elk Habitat Suitability – Public Lands

We created an HSI model using 8 dominant cover types (i.e., aspen, northern hardwoods/maple, oak, other hardwoods, upland conifers, cedar, other lowland conifers, openings) in our study area as identified using MDNR forest inventory data to quantify elk habitat suitability on public lands in Michigan. Michigan DNR forest inventory data are maintained through field inventories of designated forest compartments on a 10-year rotation, and contain information describing key forest stand attributes (e.g. species, age, basal area, percent canopy closure, management strategy) that allowed us to quantify elk habitat suitability on public lands. All MDNR forest stands were categorized into cover types (Table 1.1) using ArcGIS version 10.6.1 (Environmental Systems Research Institute, Redlands, CA, USA). We assigned suitability values (SV) ranging from 0 (unsuitable habitat) to 1 (suitable habitat) based on the ability of each cover type to provide seasonal life requisites based on Michigan elk winter and spring habitat use patterns (Beyer 1987). Individual SVs were modified for each cover type to more accurately describe suitability using key forest stand attributes identified by Beyer (1987; Table 1.2).

Table 1.1. Habitat suitability values (scale 0–1; 1 = optimum) for cover types supporting each life requisite (i.e., winter thermal cover, winter food, and spring food) for elk in northeastern lower Michigan on state-owned public lands. Cover types selected based on MDNR forest inventory data. Adapted from Beyer (1987).

Cover type	Winter thermal cover	Winter food	Spring food
Aspen	0.3	1.0	0.7
Northern hardwoods/maple	0.3	1.0	0.5
Oak	0.3	0.7	0.4
Other hardwoods	0.3	0.5	0.3
Cedar	1.0	1.0	0.7
Upland conifers	0.5	0.7	0.5
Other lowland conifers	1.0	0.2	0.5
Openings	0.0	0.0	1.0

Table 1.2. Elk habitat suitability value modifiers for elk life requisites in northeastern lower Michigan on state-owned public lands. Adapted from Beyer (1987).

Winter thermal cover	Winter food/Spring food
Width of conifer stands	Age of aspen stands
% canopy closure of conifer stands	Density of cedar stands
Even/unevenaged management of conifer stands	Density of hardwood stands
Stand age of conifers	
Hardwood stand basal area	
Hardwood dbh	
Presence of conifer understory in hardwood stands	

Similar to Beyer (1987), we determined the quality of WTC that conifer stands provide for elk to be a function of stand width (MOD_{StWid}), percent canopy closure ($MOD_{\%CC}$), whether a stand has been managed to be even or uneven-aged ($MOD_{Even/Uneven}$), and the age of a stand if even-aged (MOD_{ConAge}).

$$SV_{WTC\ Conifer} = SV_{cover\ type} \times MOD_{StWid} \times MOD_{\%CC} \times MOD_{Even/Uneven} \times MOD_{ConAge}$$

Stand width was used based on the environmental differences (i.e., temperature, wind currents, snow depths) between stand edge and interior, and the necessity of adequate stand size to accommodate elk herding behavior (Beyer 1987). Beyer (1987) determined the optimal stand width for elk to be 150 m or greater, with stands providing proportionally lower value as they decrease in size. We measured individual stand widths using ArcGIS, and considered the largest diameter within each stand to be its maximum width (i.e., to avoid assigning higher values to stands that were wider in one direction than another). Stand canopy closure of conifer stands is essential to elk for thermoregulation and energy conservation provided by a 75–100% complete canopy closure (Verme 1965, Thomas et al. 1979). We identified stands managed under even-aged management strategies due to their ability to modify wind currents and reduce heat loss to elk (Verme 1965). Additionally, stand age was used for even-aged stands due to the relationship between taller tree height and greater canopy depth, thus increasing the ability of a stand to reduce snow depths and modify stand conditions at ground level (Beyer 1987). According to Johnston (1977), conifers ≥12 m in height provide optimal thermal cover. Therefore, we used site index curves for lowland conifer species (e.g., black spruce, northern white-cedar, balsam fir) in the eastern United States to determine that a stand age of ≥33 years provides optimal WTC for elk in Michigan (Carmean et al. 1989). Percent canopy closure, stand management strategy, and stand age were determined using MDNR forest inventory data.

We determined the quality of WTC that hardwood stands provide using a function of the average basal area of a stand (MOD_{BA}), tree size (dbh) (MOD_{DBH}), and presence of a conifer understory in a stand (MOD_{ConUnd}, Beyer 1987).

$$SV_{WTC\ Hardwood} = SV_{cover\ type} \times MOD_{BA} \times MOD_{DBH} \times MOD_{ConUnd}$$

We used basal area (MOD_{BA}) and maximum tree size (MOD_{DBH}) of hardwood stands to modify WTC suitability values due to the ability of tree trunks to reduce air movements within forest stands (Beyer 1987). Similar to Beyer (1987), we used the MDNR's forest inventory defined equivalent value of a well-stocked stand (i.e., basal area of $16 m^2$/ha or greater) as the optimal basal area to provide WTC for elk. Additionally, elk have been shown to select bed sites next to the largest diameter trees in forest stands during winter (Beall 1974). Therefore, we identified hardwood stands with tree sizes of ≥35 cm dbh to be optimal for providing WTC (Beyer 1987). However, basal area and dbh modifiers were only used if a conifer understory was present to provide horizontal cover and reduce air movements (Beyer 1987). Hardwood stands without conifers in the understory were considered to have no WTC value for elk. We used MDNR forest inventory data to identify basal area, tree dbh, and presence of conifer understory.

According to Beyer (1987), the quality of aspen as a WF or SF source for elk is a function of aspen stand age.

$$SV_{WF\ Aspen} \textit{ and } SV_{SF\ Aspen} = SV_{Aspen} \times MOD_{AspenAge}$$

Aspen is a valuable winter and spring food source for elk in Michigan, but previous research found declines in browse use as age of aspen increased (Campa 1989, Campa et al. 1993, Raymer 2000). Aspen stands 1–2.5 m tall (i.e., age 1–3 years) are ideal for normal browsing with only larger animals being able to access browse from trees >3 m in height (Beyer 1987). We determined aspen stands <7 years of age to have winter and spring food value for elk.

The quality of cedar as a WF or SF source for elk also is a function of stand age (Verme 1965).

$$SV_{WF\ Cedar}\ \textit{and}\ SV_{SF\ Cedar} = SV_{Cedar} \times MOD_{CedarAge}$$

Verme (1965) found cedar stands between 5–9 years-old provide the best quality and quantity of food for deer in the Upper Peninsula of Michigan. While elk can reach higher for browse, Beyer (1987) suggested greater snow depths in the Upper Peninsula than in the Northern Lower Peninsula would negate the height advantage for reaching browse. We used MDNR forest inventory data to identify aspen and cedar stand ages on public land. Additionally, the amount of WF and SF that upland conifer stands can provide is a function of the presence of hardwood species used as browse by elk in the understory (Beyer 1987). We considered upland conifer stands without hardwood species in the understory to have no WF or SF value for elk.

Using ArcGIS, we created elk habitat suitability maps for public lands for each life requisite at a resolution of 30 x 30 m (i.e., to remain consistent with the resolution of subsequent models). We used a roving window with a focal mean function to recalculate suitability for each life requisite to consider the spatial influence of elk movement patterns. Our roving window sizes (i.e., 1,053 m for WTC and WF, 1,690 m for SF) were based on the mean maximum daily movement distance (i.e., diameter) of radio-collared elk during winter 2016–2018 for WTC and WF, and spring 2016–2018 for SF (Table 1.3). Additionally, we calculated the amount of area (km^2) represented by each suitability value (i.e., within our range of 0–1) to assess the distribution of habitat suitability for each life requisite.

Elk Habitat Suitability – Private Lands

To quantify elk habitat suitability on private lands in Michigan, we classified cover types for our entire study area (i.e., private and public lands) using satellite imagery to identify forest stands since forest inventory data equivalent to those for state lands do not exist for private lands. We used National Agriculture Inventory Program (NAIP) imagery (1 x 1 m, 2012) purchased through the U.S. Department of Agriculture in ArcGIS to identify 5 cover types (i.e., aspen, hardwoods, upland conifers, lowland conifers, openings) based on visual characteristics (e.g., shape, texture, color). We used the Image Classification toolbar in ArcGIS and delineated 10–15 training samples (i.e., polygons) representing a minimum of at least 5% of each cover type through MDNR forest inventory data in public land areas. We used the Maximum Likelihood Classification Tool to classify the NAIP imagery into our 5 cover types. To remove irrelevant detail and improve classification, we resampled the imagery at a resolution of 30 x 30 m. To determine the accuracy of satellite imagery classification methods, we validated each class using cover type descriptions from MDNR forest inventory data for all public lands (664.9 km^2) found within our study area.

Cover types were assigned SVs (Table 1.4) based on Michigan elk winter and spring habitat use patterns determined by Beyer (1987). We modified upland and lowland conifer cover types for percent canopy closure using the Landscape Fire and Resource Management Planning Tools (LANDFIRE) Forest Canopy Cover (CC) layer from 2012 (available at https://www.landfire.gov/cc.php). We applied roving window sizes described in our previous model to recalculate suitability for each life requisite, and produced elk habitat suitability maps and plotted the distribution of HSI values by area (km^2) for public and private lands for each suitability map.

Table 1.3. Mean maximum daily movement diameter (MDMD) of GPS-collared elk during winter (17 Feb–20 Mar, 2016; 21 Dec–20 Mar, 2017–2018) and spring (21 Mar–20 Jun, 2016–2018) in northeastern lower Michigan.

Season	N	Days monitored	MDMD (m)	SE
Winter	46	6,328	1,053.1	8.6
Spring	47	8,798	1,689.6	10.0

Table 1.4. Habitat suitability values (scale 0–1; 1 = optimum) for cover types supporting each life requisite (i.e., winter thermal cover, winter food, and spring food) for elk in northeastern lower Michigan on private lands. Cover types selected based on satellite imagery classification. Adapted from Beyer (1987).

Cover type	Winter thermal cover	Winter food	Spring food
Aspen	0.3	1.0	0.7
Hardwoods	0.3	0.8	0.5
Upland conifers	0.5	0.7	0.5
Lowland conifers	1.0	0.7	0.6
Openings	0.0	0.0	1.0

Elk Habitat Potential

We quantified elk habitat potential by delineating habitat types for northern lower Michigan using a procedure similar to the one described by Felix et al. (2004). We overlaid 3 digital spatial datasets in ArcGIS software (Scheme 1.1). Essentially, habitat types were the intersection of landtype associations (LTAs), soils, and vegetation (Felix et al. 2004). The landtype associations layer (Corner et al. 1999) helped describe plant species recruitment patterns and direction of compositional and structural change across a landscape (Cleland et al. 1993) based on landform and topographic characteristics. We used SSURGO soils data (Natural Resources Conservation Service 2010) to describe soil moisture and texture, which limit potential vegetation types and are important characteristics for classifying habitat types (Kotar and Burger 2000). We identified specific land cover classes in various seral stages within habitat types using land cover classifications from the Integrated Forest Monitoring, Assessment, and Prescription (IFMAP) data (MDNR 2003) at a resolution of 30 x 30 m.

We converted the soils and LTAs from vector data models to raster and assigned grid codes based on texture and moisture (soils) and landform (LTAs). All datasets were combined using the Raster Calculator in ArcMap. Habitat types were identified using habitat type classification guides (i.e., Coffman et al. 1980, Burger and Kotar 1999) and a hierarchical decision protocol whereby soils and LTAs determined possible successional pathways and the vegetation dataset (MDNR 2003) validated the habitat type assignment. In cases where discrepancies were identified based on inaccuracies and inconsistencies in the datasets, we designated habitat types by evaluating the landscape patterns of vegetation composition and structure using high resolution (1 x 1 m) imagery purchased from the USDA (National Agriculture Imagery Program 2012).

We assigned SVs to each successional stage for each habitat type based on the maximum value of suitability provided by cover types for each elk life requisite (i.e., based on prior research by Beyer [1987]). Habitat potential was determined by selecting the highest SV of any successional stage for each habitat type, and habitat potential maps were created for each life requisite at a resolution of 30 x 30 m to reflect elk movements and feeding behavior. Additionally, we identified key public land areas for elk habitat management focus where current habitat suitability is low (i.e., ≤0.33) and habitat potential is high (i.e., >0.66).

RESULTS

Elk Habitat Suitability – Public Lands

We identified 8,625 cover type polygons from MDNR forest inventory data for public lands within the Michigan elk range. The most abundant cover types on public lands (664.9 km^2) were aspen (25.43%, 163.97 km^2), upland conifers (23.09%, 148.86 km^2), and northern hardwoods/maple (15.36%, 99.05 km^2), with openings (i.e., maintained wildlife openings, natural grasslands, old field grasslands), other lowland conifers, cedar, other hardwoods, oak, water, and other making up ≤10% of public lands, respectively.

For WTC, approximately 79.06% (509.74 km^2) of public lands were identified as areas with low suitability (i.e., 0–0.33), 16.88% (108.87 km^2) were medium suitability (i.e., 0.34–0.66), and 4.06% (26.16 km^2) were high suitability (i.e., 0.67–1; Figure 1.2). The primary areas of high suitability were cedar (i.e., 52.33%, 13.69 km^2) and other lowland conifer (i.e., 41.74%, 10.92 km^2) stands located in large, isolated clusters (i.e., 5–13 km^2) in the northern and southern portions of public lands (Figure 1.2). For WF, approximately 40.55% (261.46 km^2) of public lands were identified as areas with low suitability, 44.61% (287.66 km^2) were medium suitability, and 14.83% (95.64 km^2) were high suitability (Figure 1.2). The primary areas of high suitability were northern hardwoods/maple (i.e., 60.62%, 57.98 km^2), upland conifer (i.e. 20.19%, 19.31 km^2), and aspen (i.e. 6.07%, 5.81 km^2) stands located throughout public lands (Figure 1.2). For SF, approximately 32.53% (209.74 km^2) of public lands were identified as areas with low suitability, 66.4% (428.15 km^2) were medium suitability, and 1.07% (6.88 km^2) were high suitability (Figure 1.2). The primary areas of high suitability were openings (i.e., 65.35%, 4.5 km^2) located in the central west portion of public lands, and northern hardwoods/maple (i.e., 33.09%, 2.28 km^2) stands that were interspersed among those openings (Figure 1.2).

Elk Habitat Suitability – Private Lands

Cover type classification distributions for private lands (555.1 km^2) were hardwoods = 40.6% (225.2 km^2), openings = 20% (111.3 km^2), upland conifers = 16.6% (92.3 km^2), aspen = 14.3% (79.6 km^2), and lowland conifers = 6.5% (36.4 km^2). Our satellite imagery classification method was moderately successful for upland conifers (66.1% accuracy), hardwoods (57.6%), openings (56.8%), and lowland conifers (54.8%) on public lands where MDNR cover type data was available for determination of accuracy (Table 1.5). Classification accuracy of aspen stands on public lands was lower (36.4%) primarily due to mature aspen stands being visually indistinguishable from mature hardwood stands (i.e., 45.4% were classified as hardwoods).

For WTC, approximately 66.1% (367 km^2) of private lands were identified as areas with low suitability, 33.8% (188 km^2) had medium suitability, and 0.1% (<1 km^2) had high suitability (Figure 1.3). The paucity of private land areas with high suitability for WTC can be attributed to the absence of mature cedar and lowland conifer stands that were large enough to provide high suitability after roving window averaging. For WF, approximately 2% (11 km^2) of the public lands were identified as areas with low suitability, 53.5% (297 km^2) had medium suitability, and 44.5% (247 km^2) had high suitability (Figure 1.3). Most of the high suitability areas were hardwood (i.e., 55.8%, 139 km^2) and aspen (i.e., 19.2%, 48 km^2) stands found throughout private lands, and when combined account for over half (i.e., 52.6%) of all private land cover types. For SF, we found no areas with low suitability, 82.6% (459 km^2) had medium suitability, and 17.4% (96.5 km^2) had high suitability (Figure 1.3). The majority of areas with high suitability were openings (i.e., 44.6%, 43 km^2) found in clusters throughout private lands.

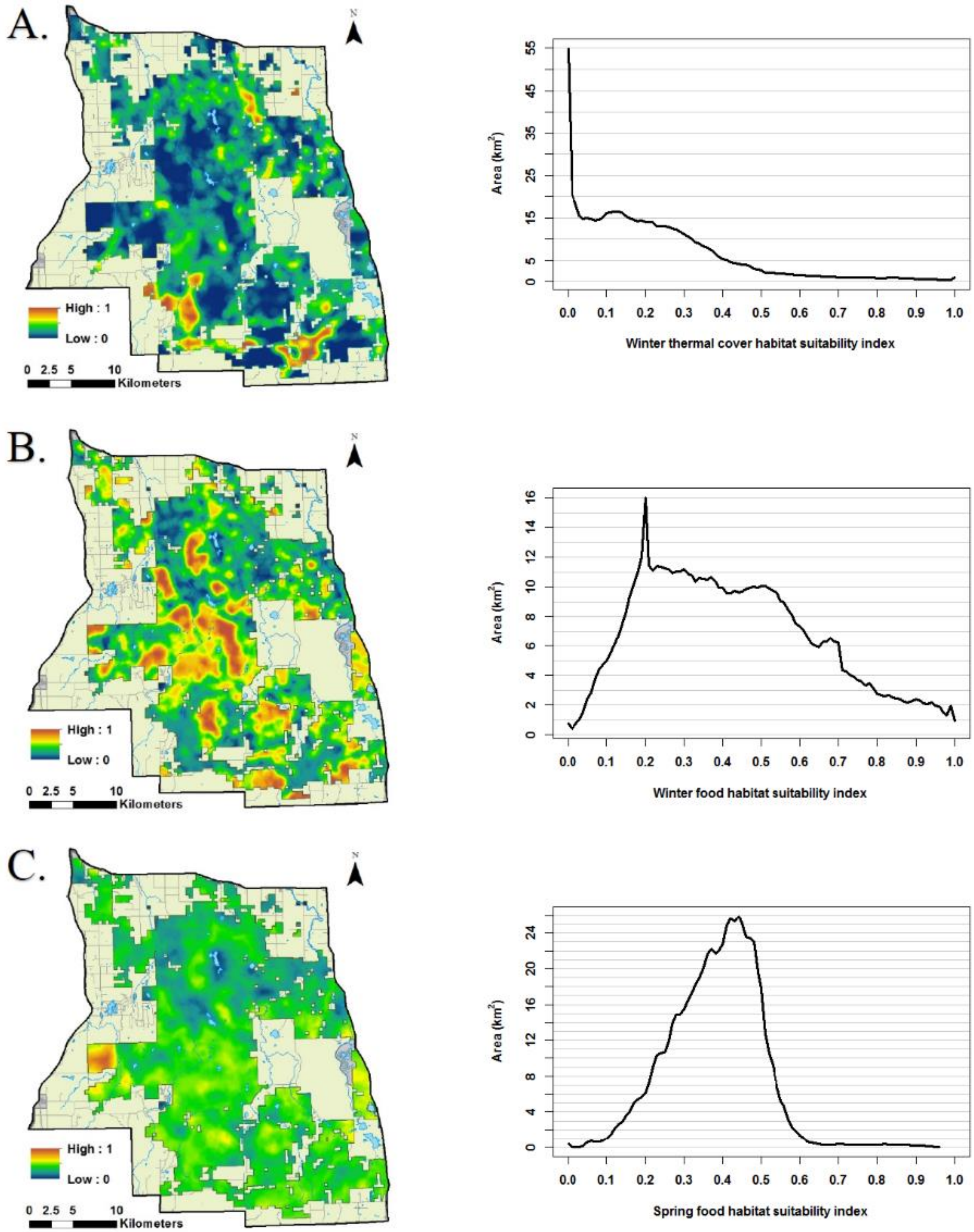


Figure 1.2. Distribution of elk winter thermal cover habitat suitability (A), winter food habitat suitability (B), and spring food habitat suitability (C) on public lands (665 km^2) within the MDNR defined elk range (1,220 km^2) in the northern lower peninsula of Michigan. Values are based on a scale of 0–1; 1 = highest suitability.

Table 1.5. Accuracy assessment of classification methods used on National Agriculture Inventory Program (NAIP) imagery (1 x 1 m, 2012) to classify cover types (i.e., aspen, hardwoods, upland conifers, lowland conifers, openings) used in an elk habitat suitability model for private lands in northeastern lower Michigan. Reported accuracy percentages were calculated by validation of classified cover types (30 x 30 m) found within public lands (664.9 km^2) using Michigan Department of Natural Resources forest inventory cover type polygons.

Classified	Aspen[1]		Hardwoods[1]		Upland conifers[1]		Lowland conifers[1]		Openings[1]	
cover types	Pixels[2]	%	Pixels[2]	%	Pixels[2]	%	Pixels[2]	%	Pixels[2]	%
Aspen	66,366[a]	36.38	32,963	18.37	5,306	3.20	7,584	6.46	5,261	7.17
Hardwoods	82,751	45.36	103,362[a]	57.60	13,405	8.10	22,105	18.82	14,844	20.24
Upland conifers	5,014	2.75	19,527	10.88	109,492[a]	66.11	3,973	3.38	4,032	5.50
Lowland conifers	3,816	2.09	3,494	1.95	3,109	1.88	64,428[a]	54.84	7,348	10.02
Openings	24,394	13.37	19,966	11.13	34,050	20.56	19,191	16.33	41,653[a]	56.80
Water	96	0.05	121	0.07	251	0.15	203	0.17	200	0.27

[1] Cover types identified within MDNR forestry inventory data.

[2] The number of 30 x 30 m pixels contained within the classification raster.

[a] Correct classification according to cover type descriptions within MDNR forest inventory data.

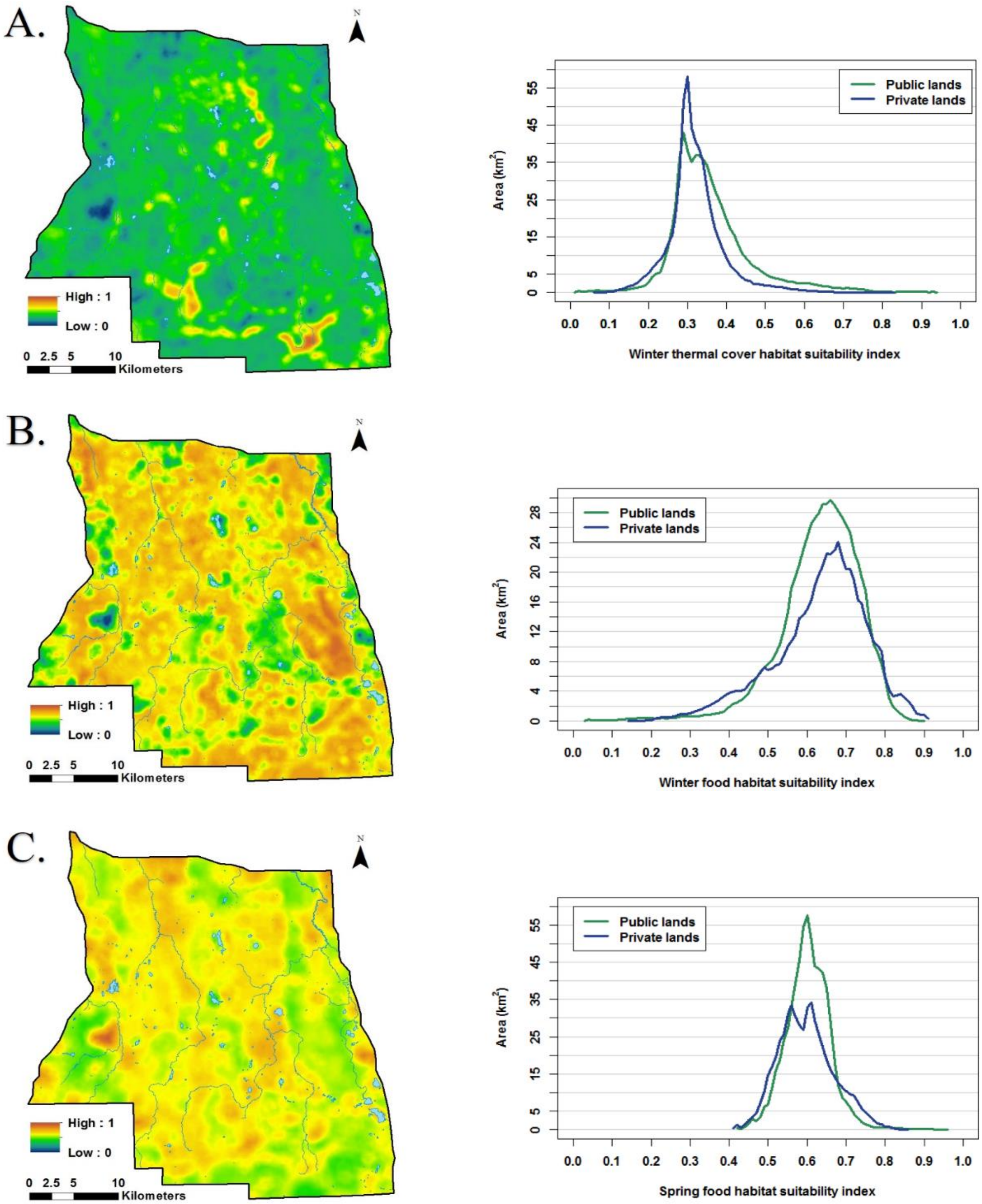


Figure 1.3. Distribution of elk winter thermal cover habitat suitability (A), winter food habitat suitability (B), and spring food habitat suitability (C) within the MDNR defined elk range (1,220 km2) in the northern lower peninsula of Michigan. Values are based on a scale of 0–1; 1 = highest suitability.

Elk Habitat Potential

We classified and delineated 13 habitat types in the Michigan elk range and determined successional pathways for each based on biotic and abiotic characteristics (i.e., LTAs, soils, and vegetation; Figure 1.4). Approximately 19% of the elk range is composed of a sandy upland dry habitat type (i.e., RO/RM/WP) in which jack pine and aspen dominate early-successional (i.e., <30 years) stages; jack pine and red pine dominate mid-successional (i.e., 30–100 years) stages; and red oak, red maple, and white pine dominate late-successional (i.e., >100 years) stages (Figure 1.4). Approximately 18.7% of the elk range is composed of a sandy upland dry-mesic habitat type (i.e., SM/Bee/H) in which aspen and white birch dominate early-successional stages; red maple, beech, and white ash dominate mid-successional stages; and sugar maple, beech, and hemlock dominate late-successional stages (Figure 1.4). Approximately 10.7% of the elk range is composed of a sandy dry habitat type (i.e., WP/RP/O/JP) in which shrubs and grasses dominate early-successional stages due to poor soil fertility; jack pine and red pine dominate mid-successional stages; and white pine, red pine, and oak dominate late-successional stages (Figure 1.4). All other habitat types each represent <10% of the elk range (Figure 1.4).

Habitat types vary in their potential to provide elk life requisites. For WTC, 5 habitat types provide maximum habitat potential (1.0), 5 provide medium potential (0.5), and 3 provide low potential (0.3). However, habitat potential was high (0.7–1.0) across all habitat types for winter and SF (Figure 1.5). Notably, all but one habitat type (i.e., WP/RP/O/JP) provide maximum habitat potential during at least one successional stage for WF. While each habitat type provides different potential across successional trajectories for each elk life requisite, general trends were evident.

	Prop.	Early	Mid	Late
	0.190	A/JP	JP/RP	RO/RM/WP
	0.187	A/Bir	RM/Bee/WA/Bas/WP	SM/Bee/H
	0.107	Shr/G	JP/RP/WP/O	WP/RP/O/JP
	0.079	A/Bir	SM/O/Bee	SM/Bee/H
	0.067	A/Bir	BF/WS/RM	H/C/BF/RM
	0.064	A	O/RM/WP	WP/RM
	0.063	A/O	O/RM/WP/BC	WP/RM/Bee/SM
	0.058	A	A/RM/WP	WP/RM/Bee/SM
	0.050	LBr/T/BA/Bir	T/BA/RM	C/BS/BF
	0.043	LBr/A/Bir/BP/BA	C/BS/BF	C/H
	0.025	LBr	BS/T/BF/C/WP	BS/T
	0.020	LBr/Bir/T/BA	T/BA/RM	C/BS/BF
	0.002	A/Bir	SM/Bee/Bas/RM/WA	SM/Bee
	0.013	Urban/Developed		
	0.025	Agriculture		
	0.007	Lake/River		

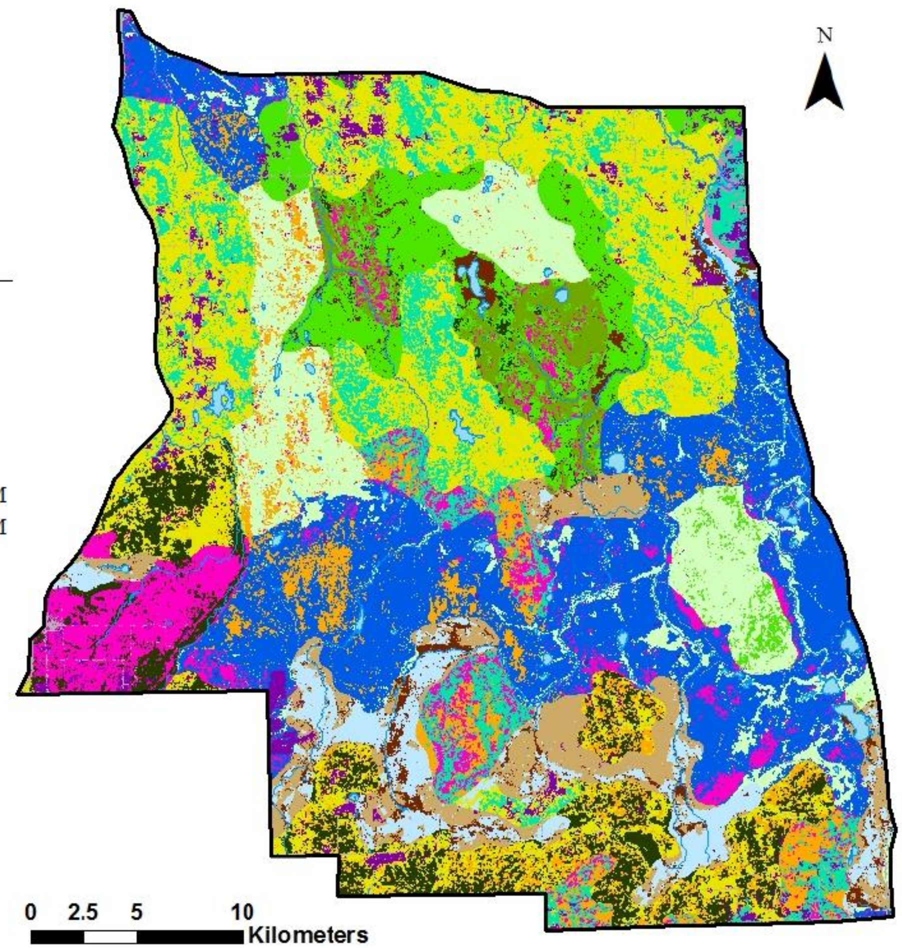


Figure 1.4. Proportion (Prop.) and location of habitat types within the MDNR defined elk range (1,220 km^2) in the northern lower peninsula of Michigan. Vegetation codes for early-, middle-, and late-successional stages are as follows: A = aspen, BA = Black Ash, Bas = basswood, Bee = beech, BF = balsam fir, Bir = white birch, BP = balsam poplar, BC = black cherry, BS = black spruce, C = cedar, G = grass species, H = hemlock, JP = jack pine, LBr = lowland brush, O = oak species, RM = red maple, RO = red oak, RP = red pine, Shr = shrub, SM = sugar maple, T = tamarack, WA = white ash, WP = white pine.

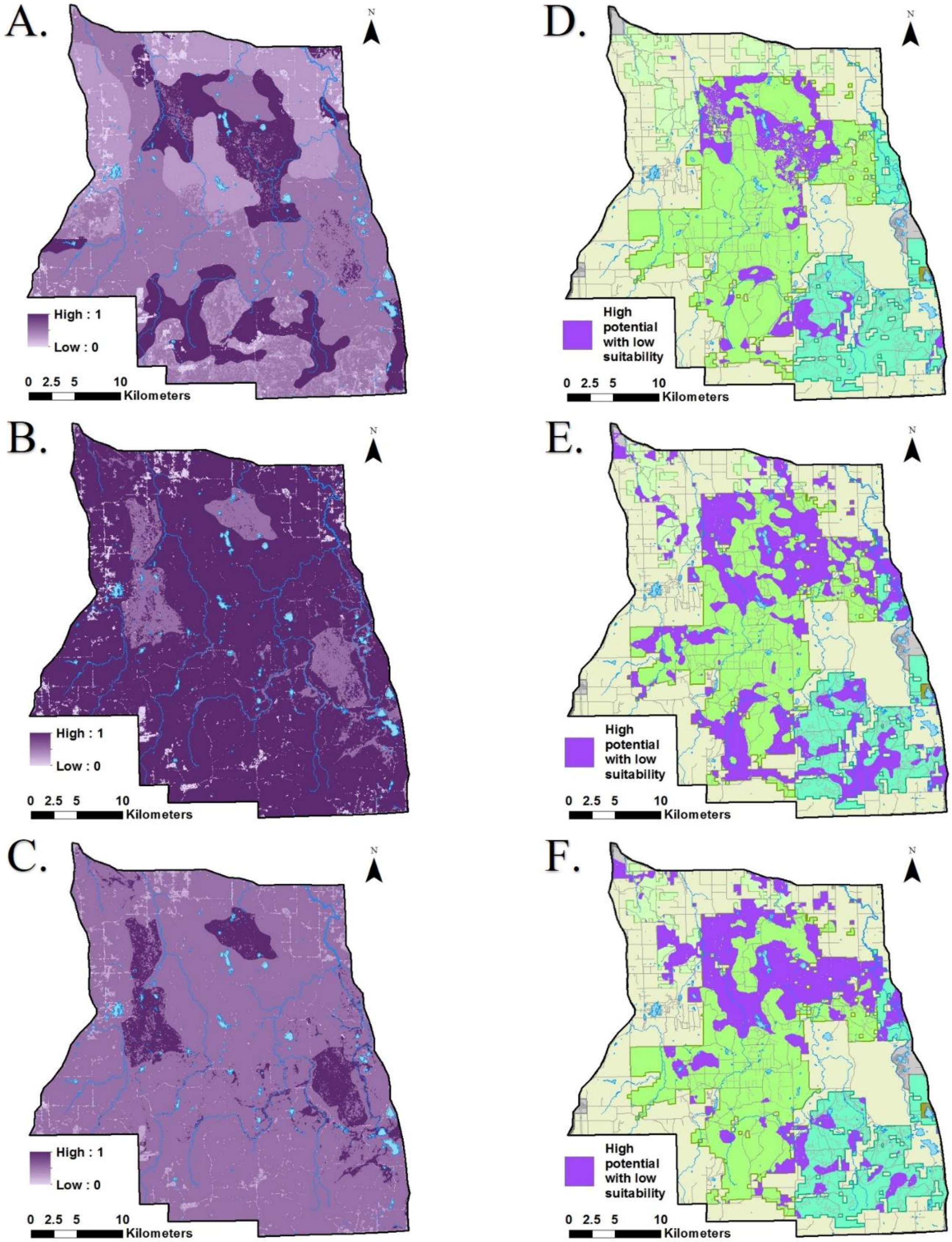


Figure 1.5. Distribution of elk winter thermal cover habitat potential (A), winter food habitat potential (B), and spring food habitat potential (C) in the MDNR defined elk range (1,220 km^2) in the northern lower peninsula of Michigan. Distribution of areas with low habitat suitability (< 0.33) and high habitat potential (> 0.66) for elk winter thermal cover (D), winter food (E), and spring food (F). Habitat potential/suitability values are based on a scale of 0–1; 1 = highest potential/suitability.

For WTC, all habitat types provide highest potential during mid to late-successional stages when lowland conifer species are present and stand canopy closure is at least 75%. Approximately 20% of the elk range has high potential (1.0) for WTC during mid to late-successional stages. For WF, approximately 71% of the elk range has high potential (1.0) in early-successional stages due to habitat types supporting young, regenerating aspen stands (i.e., <7 years-old) providing browse. Additionally, approximately 45% of the elk range has high potential (1.0) in mid to late-successional stages when northern hardwood (e.g., sugar maple, red maple, hemlock, basswood) stands provide browse, and approximately 13.8% of the elk range has high potential (1.0) during mid to late-successional stages when young cedar stands (i.e., <25 years-old) provide browse. For SF, 10.7% of the elk range has high potential (1.0) during early-successional stages when openings provide herbaceous forage. The remaining 89.3% of the elk range has high (0.7) potential during early-successional stages when regenerating aspen stands provide browse or mid to late-successional stages when young cedar stands provide browse.

To identify key public land areas for elk habitat management, we identified areas that had low habitat suitability and high potential for each life requisite (Figure 1.5). For WTC, approximately 15.2% (101 km^2) of public lands in the elk range had low habitat suitability ($\leq$0.33), but high potential. The majority of areas in low suitability were aspen (33 km^2), upland conifers (14 km^2), cedar (12 km^2), openings (12 km^2), other lowland conifers (11 km^2), and other hardwoods (11 km^2) cover types. Aspen, upland conifers, openings, and other hardwoods cover types that had low suitability were in early-successional stages of habitat types that have high potential for WTC in late-successional stages. Cedar and lowland conifers cover types that had low suitability were degenerating due to age or were too small (<50 m in diameter) in size to provide WTC for elk (Beyer 1987).

For WF, approximately 39.4% (262 km^2) of public lands within the elk range had low habitat suitability, but high potential. The majority of areas in low suitability were aspen (94 km^2), lowland conifers (39 km^2), openings (38 km^2), and cedar (38 km^2) cover types. Approximately 36% of areas that are currently in low suitability for WF were aspen stands ≥7 years-old that were too mature to provide available browse for elk (Campa 1989, Campa et al. 1993, Raymer 2000). Similarly, cedar stands with low suitability were too mature (i.e., >25 years-old) to provide WF (Verme 1965, Beyer 1987). Openings with low suitability were in habitat types that will not provide WF unless they are allowed to reach mid to late-successional stages.

For SF, approximately 32.6% (217 km^2) of public lands within the elk range had low habitat suitability, but high potential. The majority of areas in low suitability were aspen (96 km^2), upland conifers (30 km^2), openings (20 km^2), and other hardwoods (20 km^2) cover types. Similar to WF, aspen stands that had low suitability for SF were too mature (i.e., ≥7 years-old) to provide elk with ample browse. The majority of upland conifer and other hardwood stands with low suitability were habitat types that provide aspen in early-successional stages. Openings that had low suitability for SF were reduced in value due to their juxtaposition to comparatively larger areas of lower value cover types from roving window averaging.

DISCUSSION

While our analyses demonstrated the utility of integrating habitat suitability and potential models for elk habitat management planning in Michigan, other wildlife species with known habitat requirements can benefit from habitat management using this approach. For example, species of concern such as American marten (*Martes americana*) require specific structural habitat characteristics (e.g., canopy cover, tree size, coarse woody debris) within specific habitat types supporting pine-dominated vegetation types with few mixed hardwoods (Hargis and McCullough 1984, Thompson and Colgan 1994, Godbout and Ouellet 2010). A habitat potential model can be used to identify habitat types that support pine-dominated vegetation types (i.e., areas of high habitat potential), and a habitat suitability model can then be used to identify sites that are currently in low suitability within those habitat types as focus areas for marten habitat management efforts.

The spatial and temporal components of our approach may be especially useful for consideration of where and when to implement management strategies for threatened or endangered species with known habitat requirements. Habitat degradation and fragmentation are commonly cited as primary sources of species endangerment, necessitating the importance of identifying current and potential sources of habitat for threatened and endangered species (Wilcove et al. 1998, Kerr and Cihlar 2004, Schaffer-Smith et al. 2016). Linden (2011) used a habitat potential model for Canada lynx to determine potential hare and lynx densities in the Upper Peninsula of Michigan. While his model defined habitat types to identify vegetation attributes for the prediction of hare and lynx densities, it did not assign habitat suitability values to successional stages for consideration of habitat potential for life requisites of lynx. Managers could apply our approach of integrating habitat suitability and potential models to target areas of highest potential to maintain or improve lynx habitat quality for conservation efforts.

Additionally, reintroduction or restoration efforts may benefit by integrating habitat suitability and potential models. The persistence of a reintroduced population is dependent on the ability of managers to maintain the necessary habitat requirements for a given species (Armstrong and Reynolds 2012); thus, requiring collection of data to determine habitat suitability before introduction and monitoring of key habitat variables following a release. For instance, many mangers use population viability analysis (PVA) to identify key parameters (e.g., habitat restoration) that will increase the probability of success for a reintroduced species (Haines et al. 2006, Kindall et al. 2011). Some PVAs have linked estimates of habitat availability to population viability by simulating decreases in habitat quality or quantity over time (Akçakaya et al. 1995, Nickelson and Lawson 1998, Larson et al. 2004). While these examples incorporated temporal changes to habitat suitability and availability, each only addressed specific scenarios or simulations for changes to habitat. We believe using habitat types to determine potential habitat suitability for any successional stage provides the flexibility to understand the spatial and temporal dynamics of wildlife habitat for any species with known habitat requirements in any landscape.

In our case study, we determined less than half (i.e., 38%) of the Michigan elk range had high habitat suitability for at least one life requisite of elk. Conversely, nearly all (i.e., 96%) of the elk range had high habitat potential for at least one life requisite for elk. While the proportion of areas with low habitat suitability varied for each life requisite, the potential for those areas to provide habitat for elk was high (Figure 1.6). For example, habitat suitability was low for WTC on private and public lands, with only a few primary areas (26.16 km^2) of high suitability on public lands in the north and southern areas of the elk range (Figure 1.3). However, habitat types that provided high potential for WTC composed 21% (256 km^2) of the elk range; hence, only 10.2% of areas capable of providing WTC for elk were currently in high suitability. Beyer (1987) suggested that ideally elk habitat should be comprised of 10% WTC with the highest suitability (i.e., 1.0). While only 4.06% of public lands and 0.1% of private lands were determined to provide high suitability (i.e., 0.67–1.0) in our models, 16.88% of public lands and 33.8% of private lands were in medium suitability (i.e., 0.34–0.66) and should be considered valuable for providing WTC for elk. Additionally, we believe the low proportion of high suitability WTC areas in the Michigan elk range is sufficient based on observations made by Moran (1973) where elk were not observed using thermal cover until snow depths exceeded 46 cm. In Pennsylvania, elk have been found using conifer stands and lowland drainages when snow depths were ≥ 60 cm (DeBerti 2006). Additionally, Moran's (1973) findings were similar to western states where elk movements were restricted at depths of 41 cm (Sweeney and Steinhoff 1976) and 46 cm (Beall 1974, Leege and Hickey 1977). Notably, elk nearly exclusively used conifer stands when snow depths exceeded 60 cm in Glacier National Park, MT (Martinka 1976). According to NOAA (2018), snow depth records within 8 km of our study area exceeded 46 cm during 20% of days during the winters from 2008–2018. While it is vital to maintain areas that provide WTC within the elk range, the low proportion of winter days necessitating the use of WTC may allow managers to focus management efforts on maintaining and improving habitat for winter and SF for elk.

In contrast to WTC, results indicated habitat suitability for winter and SF was higher and more evenly distributed across public and private lands within the elk range. We attribute an abundance of high suitability areas to habitat management by the MDNR on public lands since the mid 1970's (MDNR 2012), private land management on club lands, and high habitat potential for winter and SF across nearly all of the elk range. The only areas without high habitat potential are developed, urban, or agricultural areas; <4%. The potential for all habitat types within the elk range to provide high suitability for winter and SF is primarily due to: 1) approximately 73.5% of the elk range composed of habitat types that support aspen; 2) approximately 24.5% of the elk range composed of a habitat type that supports openings throughout early-successional stages.

The differences between habitat suitability and potential in the Michigan elk range were due to habitat types not being in successional stages that currently provide high suitability for elk life requisites (i.e., food or thermal cover). For example, 75.3% of the elk range is composed of habitat types that support aspen during early or mid-successional stages. Aspen was the most abundant cover type on public lands within the elk range, which was consistent with the statewide distribution of forest types for the Lower Peninsula of Michigan (MDNR 2008). However, only 4.6% of aspen stands on public lands were <7 years-old and provided value for elk winter and SF in our models (i.e., the majority [70.9%] of aspen stands were 20–50 years-old). Despite the low proportion of young stands, aspen still composed 6.07% of the high suitability areas for WF. The MDNR (2012) currently manages for no net loss of aspen stands (i.e., 27% of public land forest cover types), and for numerous age classes. Harvesting an extensive number of mature (i.e., > 40 years-old) aspen stands in any year may promote an abundance of regeneration and available browse for elk and other wildlife species (e.g., ruffed grouse [*Bonasa umbellus*], white-tailed deer [*Odocoileus virginianus*]), but would reduce the amount of aspen stands available for cutting in subsequent years until harvest age is reached creating a "boom and bust" scenario for wildlife populations depending on various stages of aspen development (MDNR 2008:56, Felix-Locher and Campa 2010). While the majority of the elk range has high habitat potential due to its ability to support aspen in early successional stages, we believe the current forest management strategy to maintain no net loss of aspen of numerous age classes provides an adequate winter and SF source for elk in Michigan. Beyer (1987) described optimal elk habitat in Michigan as providing ≥15% of available cover types in highest suitability (i.e., 1.0) for WF and ≥10% of available cover types in highest suitability (i.e., 1.0) for SF. We found 14.83% of public lands (i.e., 95.64 km^2) in high suitability (i.e., 0.67–1.0) for WF with aspen contributing 6.07% (i.e., 5.81 km^2). For SF, we found only 1.07% of public lands in high suitability (0.67–1.0). However, 44.61% of public lands were found to be in medium suitability for WF with aspen contributing 21.96% (63.16 km^2), and 66.4% of public lands were found to be in medium suitability for SF with aspen contributing 15.52% (66.4 km^2). We believe the abundance of medium suitability areas for winter and SF should be considered valuable when considering the availability of food for elk. Notably, the Michigan elk population is considered healthy with a stable population size and successful hunting seasons since 1984 (MDNR 2012, MDNR 2019).

Identifying aspen stands on private lands will allow managers to realize potential areas of high suitability that may attract elk or other wildlife species from public land areas. For private lands, we found aspen only composed 14.3% of the cover types. However, our satellite imagery classification of aspen stands on public lands only classified 36.38% of aspen stands correctly, with 45.36% of aspen being misclassified as hardwoods. We attributed the misclassification of aspen to the similar appearance of hardwoods in our satellite imagery. While we recognize this as a limitation in our model, the misclassification of aspen was conservative and did not overestimate habitat suitability in our model. The misclassification of aspen to hardwoods only reduces our HSI values from 1.0 (i.e., 100% aspen) to 0.8 (i.e., 100% hardwoods) for WF and 0.7 (i.e., 100% aspen) to 0.5 (i.e., 100% hardwoods) for SF. Additionally, our inability to determine the age of aspen stands on private lands likely overestimates the suitability value of aspen stands ≥7 years of age. This is especially true for SF where all aspen stands were valued at 0.7, which likely inflated the proportion of areas in high suitability. While we are aware of these limitations in our private lands model, we believe the reduction in suitability value for 63.6% of aspen stands on private lands may more accurately represent winter and SF values for aspen on private lands when considering the aforementioned 70.9% of aspen stands within the elk range are 20–50 years-old. While we believe the misclassification error in our private lands model did not strongly affect our habitat suitability values, we advise wildlife managers to be aware of model limitations and additional information such as stand structural conditions (e.g., age) to inform habitat management decisions. However, use of data with relatively low accuracy may still be important for identifying areas of interest to improve accuracy with additional analyses, or to validate models through field sampling.

Openings have been recognized as a vital habitat component for elk in the eastern US (Devlin and Tzilkowski 1986 [Pennsylvania], Dahl 2008 [Kentucky]), and are used by elk in Michigan more often than all but regenerating deciduous and northern hardwood stands (Beyer and Haufler 1994). The MDNR (2012) actively manages public lands within the elk range to maintain 6–7% of cover types as openings (i.e., grass/upland brush). While only 1.07% of public lands and 17.4% of private lands were found to be high suitability for SF, openings accounted for most of those areas at 65.35% and 44.6%, respectively. More notably, the use of a roving window (i.e., to average habitat suitability values in consideration of elk movement patterns) reduced the amount of high suitability in areas where openings were small enough to be reduced in value by surrounding lower value cover types for SF (e.g., upland conifers). The MDNR Elk Management plan suggests that openings should be distributed across the elk range "as even as possible considering ecological conditions" (MDNR 2012:23). Openings within the elk range can vary in size (<1–57 ha) depending on management goals and site conditions (S. Heistand, MDNR, personal communication). While openings that are smaller in size than nearby larger areas of lower suitability may be reduced in value by roving window averaging and not reflect high suitability areas in our model, they accounted for 9.29% (39.77 km^2) of medium suitability areas for SF which reflects the overall value and contribution to elk habitat suitability at a landscape level.

CHAPTER 2: EXAMINING TRAIL-BASED RECREATIONAL USE PATTERNS IN TWO CONTIGUOUS STATE FORESTS WITH DIFFERENT USE REGULATIONS IN MICHIGAN

INTRODUCTION

The growing use of wild areas for outdoor, nature-based recreation has necessitated the monitoring of recreational activities and associated ecological impacts around the world (Balmford et al. 2009, Balmford et al. 2015, Cordell 2012). During 2000-2009, the number of US citizens participating in outdoor activities grew 7.5% and the number of participation days increased by 32.5% (Cordell 2012). The most recent findings by the Outdoor Foundation (2020) reported 50.7% (i.e., 153.6 million Americans) of the US population ≥ 6 years of age participated in outdoor activities in 2019, which was an increase of 1.2% from 2018. Among these trends is growth in nature-based activities with wildlife viewing, wildlife photography, off-highway vehicle driving, and physically challenging activities (e.g., kayaking, surfing, snowboarding) having the largest increases in participants and number of days per year during the first decade of the 21st century (Cordell 2012).

Nature-based recreation has been recognized as one of the fastest growing sectors of tourism (Winter et al., 2020). Consequently, numerous state and federal public lands have seen an increase in recreational users and are an increasingly important destination for tourists (Cordell 2012, Winter et al. 2020). In the US, approximately 75% of backcountry activities (e.g., backpacking, day hiking, equestrian use, mountain biking), 58% of wildlife viewing and photography, 53% of motorized activities (i.e., off-road vehicle use, snowmobiling), and 50% of hunting occurred on public lands during 2005-2009 (Cordell 2012). Notably, nature-viewing and photography were the most popular activities (i.e., approximately 10x higher than backcountry activities) on public lands with 15.1 billion days of activity reported in eastern states, and 5.2 billion days in western states (Cordell 2012).

The trend in the US of increasing outdoor recreation is evident in Michigan with 63% of its residents participating annually, which is approximately 12% greater than the national average (Outdoor Foundation 2020, Outdoor Industry Association 2017). In 2017, outdoor recreational activities in Michigan generated $26.6 billion (USD) in consumer spending, 232,000 direct jobs, $7.5 billion (USD) in wages and salaries, and $2.1 billion in state and local tax revenue (Outdoor Industry Association 2017). Outdoor recreation is a mainstay of Michigan culture and the state offers numerous opportunities for camping, hiking, hunting, fishing, wildlife viewing, cycling, equestrian use, snowmobiling, and off-road vehicle (ORV) use (MDNR 2018a). One contributing factor for these patterns in recreation is every Michigan community is located within 80.4 km of a state park or recreation area (MDNR 2018a). Michigan has approximately 32,375 km^2 of public land with the Michigan Department of Natural Resources (MDNR) managing 18,615 km^2 in its state forests, parks, game areas, and recreation areas (MDNR 2018a). Notably, Michigan's Division of Parks and Recreation provides 20,117 km of trails statewide, including 2,100 km of equestrian trails, 6,500 km of hiking trails, 2,250 km of mountain biking trails, 5,800 km of ORV trails, and 10,000 km of snowmobiling trails (MDNR 2018a). Among public lands managed by the MDNR, approximately 87% (i.e., 15,783 km^2) are composed of state forests that are managed to conserve natural resources and provide natural resource-based economic activity and recreation. Whereas Michigan's state parks and recreation areas focus on providing recreational opportunities, its state forests must balance multiple management objectives of forest "use and restoration within a framework of long-term sustainability, while also enabling an expanding diversity of uses" (MDNR 2008:xii).

Although Michigan provides numerous public lands for recreation, the presence of a visible elk (*Cervus elaphus nelsoni*) herd (i.e., approximately 1,196 elk in 2019 [unpublished data provided by MDNR]) in the Pigeon River Country State Forest (PRC) and part of the adjoining Atlanta State Forest (ASF), makes these areas an attractive destination (Hunt 2019). The use of the PRC for nature-based recreation has increased over the last 50 years with noticeable growth in visitor numbers and interest in trail-based recreational opportunities (e.g., equestrian use, mountain biking, ORV use; MDNR 2007, MDNR 2012). Increasing use of the PRC by equestrian users and ORV users was first noted in 1970, and the PRC Advisory Council helped implement plans to prohibit ORVs in 1988 and control the "dramatic increase in horseback riding" in 1994 (MDNR 2007:12).The MDNR documented increasing trends in mountain biking and wildlife viewing via recreation surveys conducted in the PRC from 1981-1982, 1986-1987, and 1997-1998 (MDNR 2007).

The PRC has different regulations for trail-based recreation than other state forests (e.g., ASF) in Michigan, due to its designation as a Special Management Unit with a "Concept of Management" (COM) created to safeguard the lower peninsula's last "big wild" from overuse and development (MDNR 2007:14). Notably, the first objective of the COM is the management of elk and their habitat to conserve the core elk range within the PRC, while its third objective is to provide recreational opportunities that maintain the PRCs wild character through control of disruptive activities (MDNR 2007). Although these objectives are not mutually exclusive, the growth in nature-based recreation in the elk range has created challenges for managers charged with balancing the PRC's COM objectives (MDNR 2007).

We examined recreation patterns in the PRC and a portion of the adjoining ASF (i.e., public lands within the Michigan elk range) to inform natural resource managers of the extent and characteristics of common summer-fall trail-based recreational activities under differing use regulations. Our objectives were to: 1) quantify the intensity, temporal characteristics (i.e., year, month, day of week, time of day), and group sizes of common types of summer-fall trail-based recreation (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) occurring in the PRC and ASF; 2) characterize differences in visitor-use patterns between the PRC and ASF; and 3) provide recommendations for sustaining diverse recreational opportunities in the PRC and ASF.

METHODS

Trail Camera Placement Protocols and Camera Settings

We evaluated 4 types of trail-based recreational use (i.e., equestrian, hiking/foot-traffic, mountain biking, ORV) within the PRC and ASF for summer and fall (i.e., May–October) during 2016–2018. We quantified these common types of recreation based on observed seasonal user trends in our study regions and due to concerns of natural resources professionals regarding their growing numbers and potential impacts to elk and other wildlife (B. Mastenbrook, MDNR, personal communication). We used 3 remote digital trail camera brands and models (i.e., RECONYX PC900 HyperFire™ Professional High Output Covert IR, RECONYX, Inc., Holmen, WI; Browning Dark Ops Elite HD, Browning, Inc., Morgan, UT; Stealth Cam model #, Stealth Cam, Inc., Grand Prairie, TX) to capture the diversity of recreation types likely to be seen in our study regions. To capture fast moving recreational users (i.e., mountain biking, ORVs) we used RECONYX trail cameras due to their fast shutter speeds, which have been found to have high detection rates for humans and large mammals (Gompper et al. 2006) and outperform other brands in multiple studies (Duke and Quinn 2008, Hughson et al. 2010, Kelly and Holub 2008). Browning and Stealth Cam trail cameras were primarily used in areas where mountain biking or ORV use was prohibited.

Each trail camera model used a passive infrared motion detector to capture motion-induced changes in ambient infrared, and a no-glow covert infrared flash to remain unobtrusive. Cameras were mounted on trees using locking cables approximately 3–5 m above the ground at distances of 5–10 m depending on availability of trees, line of sight, and ability to obscure cameras from recreational users (i.e., placement behind trees or branches, using brush to conceal cameras and locks). We verified accuracy of camera mounting positions using the aiming function to ensure high likelihood of capturing recreational users. All trail cameras were programmed to capture images 3–5 times per motion-triggered event at 1-second intervals with no delay between image captures at high sensitivity. Each camera operated 24 hours per day, and images were programmed to include the camera ID and date and time of acquisition. We used 2 different camera placement designs for monitoring recreation use to accommodate different recreation regulations for each study region.

PRC Description and Trail Camera Placement

The PRC State Forest is 458.4 km^2 of nearly contiguous land in the northeastern lower peninsula of Michigan and designated as a Special Management Unit by the MDNR (MDNR 2007) (Figure 2.1). The area that became the PRC in the early 20th century was first referred to as “The Big Wild” due to its lack of development and mosaic of numerous forest types, rolling hills, lakes and streams, and swamps that create a “variety found nowhere else” in the lower peninsula of Michigan (MDNR 2007:3). The PRC has been the core of the Michigan elk range since 1917 and provides habitat for black bear (*Ursus americanus*), bobcat (*Lynx rufus*), white-tailed deer (*Odocoileus virginianus*), ruffed grouse (*Bonasa umbellus*), American woodcock (*Scolopax minor*), brook trout (*Salvelinus fontinalis*), and many other fish and wildlife species (MDNR 2007).

In 1970, recent drillings for newly discovered oil and gas led to increased concerns of changes to the formerly quiet and undisturbed wild nature of the PRC (MDNR 2007). This industrial activity and additional concerns over expansion of campgrounds, pathways, timber harvests, wildlife cuttings, and increasing occurrences of equestrian users, ORVs, and snowmobiles culminated in the creation of the Pigeon River Country Association (PRCA). The PRCA submitted a request to designate the PRC as a special management area in 1972, which

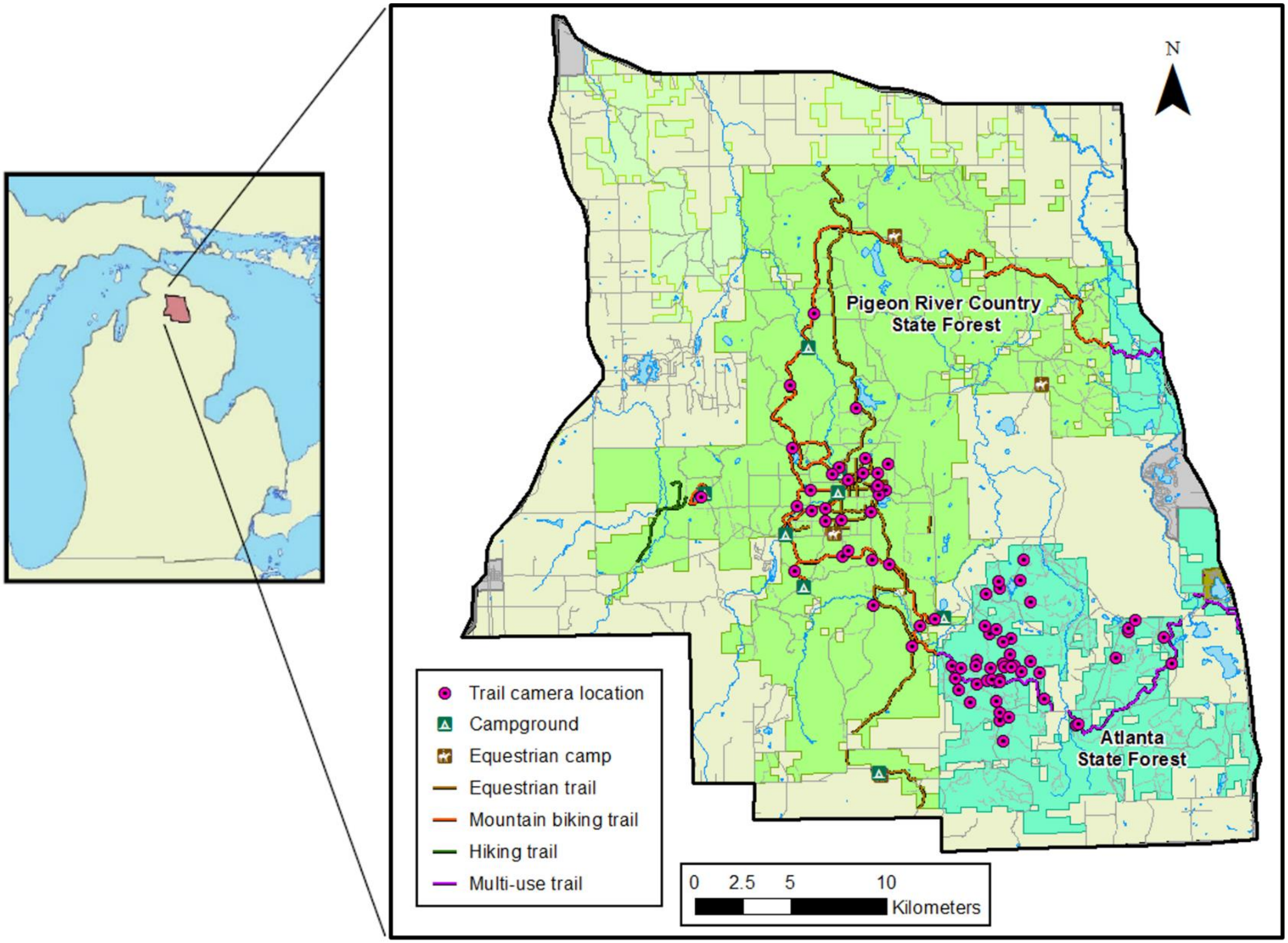


Figure 2.1. Location of designated recreational trails and campgrounds in the 1,220 km^2 Michigan Department of Natural Resources designated elk range and study area in the northern lower peninsula of Michigan. Trail camera locations shown (n=78) were during 24 May–30 September, 2018.

provided restrictions to natural resources manipulations, restricted vehicular traffic, designated its streams as “Wild Rivers”, and established a primary focus of sustainable management of resources (MDNR 2007). However, continued pressure to develop the PRC’s oil and gas wells resulted in a multi-year struggle that ended in the Michigan supreme courts. As a result, oil and gas exploration and development would be limited to the southern third of the forest and a trust fund was established in 1976 to secure lease revenues for development of new public lands for recreation. Frequent misappropriations of the funds led to a 1984 constitutional amendment that established the new Michigan Natural Resources Trust Fund (MNRTF), which was safeguarded against further diversions of funds (MDNR 2007). Since its original conception in 1976, the MNRTF has awarded (i.e., as of 20–September, 2019) approximately 1.2 billion US dollars to 2,366 projects occurring throughout all 83 counties in Michigan (MDNR 2020a), including purchases of an additional 50 km^2 for the PRC (MDNR 2007).

The PRC is a model of multiple-use land management, outlined in the management objectives and guidelines in its COM (MDNR 2007). The first objective of the COM addresses the management of elk and their habitat: “Manage the elk population and elk habitat so the Pigeon River Country State Forest remains the nucleus of Michigan’s elk herd” (MDNR 2007:14). The second objective focuses on management of habitat for other fish and wildlife species. The third objective addresses recreational use: “Provide recreational opportunities for people in keeping with the wild character of the area and to provide peace and quiet through control of disruptive activities” (MDNR 2007:14). The remaining 5 objectives address the management of game and fish species, forest and mineral resources, and protection from overuse and overdevelopment.

While the primary focus of the PRC's policies and objectives concern the management of elk and other wildlife species and their habitats, opportunities for recreation remains a concern within the COM's detailed recreational use criteria to maintain the forest's wild character. Since its conception, the PRC has been managed with more restrictions limiting development and human activity than most other state forests in Michigan to conserve its wild character from heavy use (MDNR 2007). The PRC's COM outlines its recreational use criteria for each recreational type that is common in the lower peninsula of Michigan. Notably, many of the rules, regulations, and guidelines are different from what are outlined in Michigan's State Forest Management Plan (2008), and the COM states that the PRC "cannot be all things to all recreation users" (MDNR 2007:23). For example, ORV use is prohibited in the PRC, while being restricted to forest roads and designated trails in most other state forests (e.g., ASF; MDNR 2007, MDNR 2018b; Table 2.1). Equestrian use and mountain biking are permitted on county and forest roads and designated trails, while off-road and off-trail riding is permitted in most other state forests (e.g., ASF; MDNR 2007; M. Fry, M. Monroe, MDNR, personal communication; Table 2.1).

The PRC has a well-developed and maintained network of forest roads and designated trails (Figure 2.1). According to the MDNR Resource Assessment Unit, 88% of the PRC is within 0.8 km of a road (S. Whitcomb, MDNR, personal communication). Additionally, as of 2019 there were 208.9 km of recreational trails within the PRC with 79.8 km designated for bicycling, 69.3 km designated for equestrian use, and hiking allowed on all trails. The PRC also provides 12 rustic campgrounds including 6 designated for equestrian users, of which all but 1 provides direct connections to designated equestrian trails (Figure 2.1). Notably, 2 (i.e., Elk Hill Trail/Group Campground, Johnson's Crossing Trail/Group Campground) of the 6 equestrian campgrounds are designed for large groups (i.e., a minimum of 10 people per group with a maximum campground capacity of 100 individuals) and provide amenities including fire rings, tables, toilets, potable water, and manure bunkers. Additionally, a pavilion is available at the Elk Hill Trail/Group Campground for recreational users.

We selected sites for camera placement to maximize capturing recreational user activities on trails in the PRC by focusing on intersections of trails, intersections of trails and forest roads, and trailheads (i.e., with an emphasis on trailheads and proximity to campgrounds). In 2016, we used 21 cameras (i.e., 4 Browning, 12 RECONYX, 5 Stealth Cam) in the PRC that operated 20 May–31 October. In 2017, we used 28 cameras (i.e., 18 Browning, 5 RECONYX, 5 Stealth Cam) in the PRC that operated 16 May–28 October. In 2018, we used 32 cameras (i.e., 14 Browning, 9 RECONYX, 9 Stealth Cam) in the PRC that operated 24 May–30 September (Figure 2.1). In 2018, we removed cameras at the end of September to avoid camera thefts and damage during a period of increased wildlife viewing, hunting, and logging.

Table 2.1. Trail-based recreational use regulations for primary summer-fall recreation types for the Pigeon River Country (PRC) State Forest and Atlanta State Forest (ASF) Management Units in the northern lower peninsula of Michigan.

Recreation type	PRC	ASF
Equestrian use	Limited to designated trails and all forest/county roads[1]	Permitted in all areas unless specified[2]
Hiking/foot-traffic	Permitted in all areas unless specified[1]	Permitted in all areas unless specified[2]
Mountain biking	Limited to designated trails and all forest/county roads[1]	Permitted in all areas unless specified[2]
ORV use	Prohibited within the PRC[1]	Limited to designated trails and all forest/county roads, except for hunters attempting to retrieve deer, elk, or bear at speeds of 8 kph or less[3]

[1] (MDNR 2007)
[2] (M. Fry, M. Monroe, MDNR, personal communication)
[3] (MDNR 2018b)

ASF Description and Trail Camera Placement

Approximately 168 km^2 of the Michigan elk range is in the ASF (Figure 2.1). Located adjacent to the southwestern edge of the PRC, the ASF shares many of the same geographic features and communities of plant, fish, and wildlife species. However, the Michigan State Forest Management Plan (MDNR 2008) directs the management of fish and wildlife populations and habitats, and the Michigan Statewide Outdoor Recreation Plan (MDNR 2018a) directs recreational use in the ASF. Hence, there are differences in opportunities and policies for recreation use between the ASF and PRC. For example, ORV use is permitted on all forest roads and trails within the ASF (MDNR 2018b), and equestrian users and mountain bikers are permitted to ride on all forest roads, recreational trails, and off-trail anywhere within the forest (M. Fry, M. Monroe, MDNR, personal communication; Table 2.1). The ASF has very few designated trails (i.e., 29.9 km), compared to the PRC, for recreation with only one primary trail running west from the PRC and ending in an array of short trails near the eastern edge of the elk range (Figure 2.1). Additionally, there are no designated camping areas or amenities within the forest.

Due to the limited number of designated trails, we used field observations of recreational activities and camping sites and discussions with users to determine areas (e.g., county roads, forest roads, forest edges) where we likely would observe the greatest intensity of trail-based recreational use. In 2016, we used 16 cameras (i.e., 5 Browning, 3 RECONYX, 8 Stealth Cam) that operated 20 May–31 October. In 2017 and 2018, we used a camera movement sampling design to evaluate additional locations throughout the field season to increase the probability of capturing a greater number and diversity of recreational events. Cameras that failed to capture recreation images after 2 weeks or captured < 10 images over a 3-week period were moved to a new location. Additionally, we relocated cameras near (i.e., 50–200 m) cameras that consistently captured images (i.e., reflecting high-use areas), but in areas that might capture riding behavior that was not commonly observed (e.g., riding along forest edges instead of forest roads, edges of forest clear-cuts or wildlife openings). In 2017, we used 32 cameras (i.e., 15 Browning, 9 RECONYX, 8 Stealth Cam) during 16 May–28 October, and in 2018 we used 43 cameras (i.e., 36 Browning, 4 RECONYX, 3 Stealth Cam) during 24 May–30 September (Figure 2.1). In 2018, we removed cameras at the end of September to avoid camera thefts and damage during a period of increased wildlife viewing, hunting, and logging.

Trail Camera Data Collection and Analyses

We checked cameras weekly during May–August and bi-weekly during September–October throughout 2016–2018. We recorded camera ID, date, time, recreation type, and group size for each image. We removed images that contained no recreational users or when recreation type could not be determined from analysis (e.g., blurred image, majority of user was out of image frame). A recreation event was defined as any number of individuals of the same recreation type passing a camera in the same direction within a 5-minute period. Individuals or groups that passed a camera in any direction > 5 minutes after their initial pass were counted as separate events. However, individuals or groups that turned around in front of or passed the same camera in the opposite direction within a 5-minute period were not counted as separate events (Coltrane and Sinnott 2015). Recreation events were sorted by study region (PRC, ASF), type (equestrian use, hiking/foot-traffic, mountain biking, ORV use), and categorized by year (2016–2018), month (May–Oct), day of week, and time of day (hour: 0–23).

To compare recreational intensity between regions for each temporal category, we divided the number of recreation events by the total number of operational camera hours to correct for differences in camera operating hours between regions and among operating days, months, and years. We referred to the quotients as relative recreational intensity (RRI; i.e. the number of recreation events per camera hour during each temporal category, respectively). We did not calculate RRI for time of day since we monitored 24 hours per day and the number of camera hours per time of day was equivalent for each hour interval (0–23). To evaluate recreational user trends for peak individual days of use during 2016–2018, we extracted the outliers (i.e., > Q3 + 1.5 × interquartile range [IQR]) of median daily RRI values for each study region and evaluated the distribution of days occurring during each study year, month, day of the week, holiday weekends, and for each recreation type. Analyses were conducted in R (R Core Team 2018) and figures were produced using the ggplot2 package (Wickham 2016).

To determine which variables were most predictive of recreational intensity, we used a generalized linear mixed model (GLMM) with a Poisson distribution for each region. To standardize evaluation periods among years, we removed data prior to 24–May (i.e., our latest start date among 2016–2018) and after 30–September (i.e., we did not monitor recreation during October 2018) from 2016 and 2017. Additionally, we modified the category for time of day to 3 6-hour periods (i.e., 5:00–10:59, 11:00–16:59, 17:00–23:00) to avoid model errors for consistent periods of inactivity (i.e., 2% of recreation events during 2016–2018 occurred from 23:00–4:59). Thus, we defined the response variable as the mean number of events detected during each 6-hour period within a given time period (e.g., month, day of week). Our models' fixed effects included variables for recreation type (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use), year (i.e., 2016–2018), month (i.e., May–September), day of week, time of day (i.e., 5:00–10:59, 11:00–16:59, 17:00–23:00), the two-way interactions between each variable, and a random effect of the number of operational camera hours for a given day to account for variability. We did not include ORV use in the PRC model since ORV use is prohibited and only accounted for 0.6% of recreation events in the PRC during our study.

Our GLMM outputs (i.e., emmeans) were the logmean number of events during all 6-hour periods for a given selection of the aforementioned variables (e.g., logmean number of mountain biking events occurring during May of 2017 in the PRC). Emmeans were obtained by averaging each level of aforementioned variables that was not currently being considered (e.g., the emmean for mountain biking events occurring during May of 2017 was obtained by averaging over the levels of day of week and 6-hour periods). We used post-hoc Tukey's pairwise comparison tests to interpret GLMM results for each variable and the interactions between variables. To determine which variables had the most effect on detection of a recreation event, we compared the magnitudes of F values for each independent variable. To make model outputs more informative, we back-transformed emmeans to represent the actual estimated mean number of events occurring during a 6-hour period for a given combination of variables (i.e., hereafter referred to as MN6HR). Analyses were conducted in R (R Core Team 2018) using the lme4 (Bates et al. 2015) and emmeans (Lenth 2020) packages.

To examine the number of events occurring throughout the day at a finer scale than we used in our GLMMs (i.e., 6-hour intervals), we evaluated for differences among the hourly distributions (i.e., 1-hour intervals) of recreation events for each recreation type using non-parametric Kruskal-Wallis (KW) tests. We used the number of events during 1-hour intervals as the response variable and temporal categories (i.e., year, month, day of week, time of day) as independent variables, and used post-hoc pairwise comparison tests to interpret model results among hours and recreation types (Siegel and Castellan 1988).

We examined group sizes (i.e., number of users during a recreation event) of recreational users based on previous findings of increased flight distances and decreased observations of wildlife with increased visitor group sizes (Frid and Dill 2002, Hamr 1988, Remacha et al. 2011). To evaluate differences in group size among temporal categories (i.e., year, month, day of week, time of day) for each recreation type, we used KW tests with group size as the response variable and temporal categories as independent variables. We used post-hoc pairwise comparison tests to interpret model results among temporal categories and recreation types. To evaluate the temporal characteristics for the largest group sizes of each recreation type, we extracted the outliers (i.e., $> Q3 + 1.5 \times IQR$) of median group sizes for each recreation type in each study region. We used KW tests for time of day and group size analyses to avoid violating assumptions of normality for parametric tests. We used an alpha level of 0.05 for all tests for significance. Analyses were conducted in R (R Core Team 2018) using the pgirmess (Giraudoux 2018) package.

RESULTS

Relative Intensities, Temporal Characteristics, and Group Sizes of Recreational Users in the PRC

Evaluation of recreational intensity in the PRC

We captured 11,412 recreation events during 263,664 hours of monitoring in the PRC from 2016–2018 (Table 2.2). We censored 17 events due to inability to determine recreation type. The overall RRI (i.e., relative recreational intensity) was 0.043 (i.e., events per camera hour) and the overall MN6HR (i.e., mean number of events during a 6-hour period) was 0.829. Time of day had the most effect on detection of a recreation event within a 6-hour period followed by recreation type, month, day of week, and year (Table 2.3). Equestrian use was the most frequently detected type of trail-based recreation (i.e., RRI = 0.025, MN6HR = 2.088), followed by hiking/foot-traffic (i.e., RRI = 0.015, MN6HR = 1.208), mountain biking (i.e., RRI = 0.003, MN6HR = 0.226), and ORV use (i.e., RRI < 0.001) (Table 2.4).

Evaluation of recreational intensity by year and month in the PRC

Total (i.e., all trail-based recreation types) annual RRI was less in 2018 (0.037) than 2016 (0.047) and 2017 (0.046), and the total MN6HR was less ($p < 0.05$) in 2018 (0.556) than 2016 (0.944) and 2017 (1.084) (Table 2.2). Additionally, the annual RRI and MN6HR were least during 2018 for all recreation types (Table 2.4). Evaluation of recreational intensity by month indicated September had the greatest total RRI each year, and the overall MN6HR was greater ($p < 0.05$) for September (1.597) than all other study months (May = 0.765, June = 0.647, July = 0.596, August = 0.828) during 2016–2018 (Table 2.2). Further evaluation of less recreational intensity during 2018 demonstrated that May, June, July, and August total RRIs were less than identical months in 2016 and 2017 (Table 2.2). Additionally, the total MN6HR for June (0.345), July (0.328), and August (0.536) of 2018 were less ($p < 0.05$) than 2016 (i.e., June = 0.927, July = 0.622, August = 0.962) and 2017 (i.e., June = 0.848, July = 1.038, August = 1.099).

Equestrian use had the greatest mean RRIs among recreation types during May, June, September, and October, while hiking/foot-traffic was greatest during July and August (Figure 2.2). Notably, the RRI for equestrian use and hiking/foot-traffic were always greater than mountain biking and ORV use which had the least RRIs, respectively for each month during each year of our study. Further evaluation of recreation types during each month of each year indicated September had the greatest RRIs for each recreation type, followed by May and October for equestrian use and July and October for hiking/foot traffic (Table 2.4). Monthly mountain biking RRIs were inconsistent among years apart from September having the greatest RRI each year. We found similar patterns among recreation types for 2016 and 2017 with noticeable differences in 2018. For example, the monthly RRI for hiking/foot-traffic and mountain biking for each month during 2018 was less than 2016 and 2017 (Table 2.4). For mountain biking, the MN6HR for all months in 2018 were less ($p < 0.05$) than 2016 and 2017. Additionally, monthly 2018 RRIs for equestrian use were less than 2016 and 2017 in May, June, and July, before increasing in August and September to the greatest RRIs for each type during each respective month between study years (Table 2.4).

Table 2.2. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5 minute period) and recreational intensity (i.e., RRI, MN6HR) captured by remote digital trail cameras on public lands within the Pigeon River Country (PRC) State Forest and Atlanta State Forest (ASF) Management Units during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

	Camera	PRC			ASF		
Year/month	hours	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]
2016	65,832	3,105	0.047	0.944	966	0.021	0.229
May[3]	3,552	229	0.064	0.921	31	0.072	0.621
June	10,248	392	0.038	0.927	68	0.010	0.208
July	11,280	368	0.033	0.622	75	0.010	0.197
August	12,936	350	0.027	0.962	91	0.012	0.090
September	13,680	1,205	0.088	1.401	400	0.037	0.278
October[3]	14,136	561	0.040		301	0.027	
2017	105,504	4,878	0.046	1.084	2,294	0.021	0.264
May[4]	6,048	317	0.052	0.780	104	0.021	0.199
June	19,488	484	0.025	0.848	188	0.010	0.065
July	20,832	680	0.033	1.038	295	0.013	0.228
August	20,832	607	0.029	1.099	263	0.012	0.309
September	20,160	1,573	0.078	1.984	830	0.038	1.413
October[4]	18,144	1,217	0.067		614	0.033	
2018	92,328	3,429	0.037	0.556	1,774	0.016	0.355
May[5]	3,816	157	0.041	0.623	68	0.015	0.312
June	21,672	340	0.016	0.345	211	0.008	0.280
July	22,608	358	0.016	0.328	220	0.008	0.234
August	22,728	572	0.025	0.536	285	0.010	0.200
September	21,504	2,002	0.093	1.401	990	0.038	1.374
Total	263,664	11,412	0.043	0.829	5,034	0.019	0.278
May[3–5]	13,416	703	0.052	0.765	203	0.021	0.338
June	51,408	1,216	0.024	0.647	467	0.009	0.156
July	54,720	1,406	0.026	0.596	590	0.010	0.219
August	56,496	1,529	0.027	0.828	639	0.011	0.177
September	55,344	4,780	0.086	1.597	2,220	0.038	0.814
October[3–5]	32,280	1,778	0.055		915	0.031	

Table 2.2. (cont'd)

[1] Number of recreation events per camera hour (i.e., RRI = Rec. events/Camera hours).
[2] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model.
[3] Trail cameras operated from 20–May to 31–October, 2016.
[4] Trail cameras operated from 16–May to 28–October, 2017.
[5] Trail cameras operated from 24–May to 30–September, 2018.

Table 2.3. Independent variable F-values produced by generalized linear mixed models with Poisson distributions to determine which variables had the most effect on detection of a recreation event within a 6-hour period in the Michigan elk range (i.e., Atlanta [ASF] and Pigeon River Country [PRC] State Forest management units) during 2016–2018.

Variables	Df	Sum sq.	F-value
PRC			
Recreation type[1]	2	2030.3	1015.1
Year[2]	2	44.1	22.0
Month[3]	4	2927.3	731.8
Day of week	6	1442.6	240.4
Time of day[4]	2	2275.9	1137.9
ASF			
Recreation type[1]	3	1130.8	376.9
Year[2]	2	12.9	6.4
Month[3]	4	1178.1	294.5
Day of week	6	675.3	112.6
Time of day[4]	2	497.6	248.8

[1] Equestrian use, hiking/foot-traffic, mountain biking, ORV use; Off-road vehicle use (ORV) was not included in the PRC model due to insufficient sample size.
[2] 2016–2018
[3] May–September
[4] Six-hour intervals (i.e., 5:00–10:59, 11:00–16:59, 17:00–23:00)

Table 2.4. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5-minute period) and recreational intensity (i.e., RRI, MN6HR) for recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) captured by remote digital trail cameras on public lands within the Pigeon River Country State Forest management unit during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

	Camera	Equestrian use			Hiking/foot-traffic			Mountain-biking			ORV use		
Year/month	hours	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]
2016	65,832	1,785	0.027	2.005	968	0.015	1.056	341	0.005	0.397	11	0.000	
May[3]	3,552	181	0.051	4.406	30	0.008	0.631	11	0.003	0.281	7	0.002	
June	10,248	210	0.020	1.514	126	0.012	1.146	55	0.005	0.460	1	0.000	
July	11,280	125	0.011	0.665	175	0.016	1.080	66	0.006	0.335	2	0.000	
August	12,936	117	0.009	1.358	174	0.013	1.352	59	0.005	0.486	0	0.000	
September	13,680	846	0.062	5.377	255	0.019	1.242	103	0.008	0.472	1	0.000	
October[3]	14,136	306	0.022		208	0.015		47	0.003		0	0.000	
2017	105,504	2,712	0.026	2.370	1,797	0.017	1.659	338	0.003	0.324	31	0.000	
May[4]	6,048	235	0.039	3.843	60	0.010	0.732	18	0.003	0.169	4	0.001	
June	19,488	244	0.013	1.425	201	0.010	1.434	39	0.002	0.299	0	0.000	
July	20,832	190	0.009	1.142	408	0.020	2.466	73	0.004	0.398	9	0.000	
August	20,832	168	0.008	1.596	359	0.017	2.112	77	0.004	0.394	3	0.000	
September	20,160	1,070	0.053	7.490	414	0.021	2.299	80	0.004	0.454	9	0.000	
October[4]	18,144	805	0.044		355	0.020		51	0.003		6	0.000	
2018	92,328	2,208	0.024	1.917	1,090	0.012	1.005	99	0.001	0.089	32	0.000	
May[5]	3,816	135	0.035	4.842	19	0.005	0.691	2	0.001	0.072	1	0.000	
June	21,672	106	0.005	0.915	200	0.009	0.689	34	0.002	0.065	0	0.000	
July	22,608	72	0.003	0.570	256	0.011	0.922	16	0.001	0.067	14	0.001	
August	22,728	331	0.015	1.229	222	0.010	1.218	11	0.000	0.103	8	0.000	
September	21,504	1,564	0.073	8.349	393	0.018	1.920	36	0.002	0.172	9	0.000	

Table 2.4. (cont'd)

Total	263,664	6,705	0.025	2.088	3,855	0.015	1.208	778	0.003	0.226	74	0.000
May[3–5]	13,416	551	0.041	4.344	109	0.008	0.683	31	0.002	0.151	12	0.001
June	51,408	560	0.011	1.254	527	0.010	1.042	128	0.002	0.207	1	0.000
July	54,720	387	0.007	0.756	839	0.015	1.349	155	0.003	0.208	25	0.000
August	56,496	616	0.011	1.386	755	0.013	1.515	147	0.003	0.270	11	0.000
September	55,344	3,480	0.063	6.953	1,062	0.019	1.764	219	0.004	0.332	19	0.000
October[3-5]	32,280	1,111	0.034		563	0.017		98	0.003		6	0.000

[1] Number of recreation events per camera hour (i.e., RRI = Rec. events/Camera hours).
[2] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model. Off-road vehicle use (ORV) is prohibited in the PRC and was not included due to insufficient sample size.
[3] Trail cameras operated from 20–May to 31–October, 2016.
[4] Trail cameras operated from 16–May to 28–October, 2017.
[5] Trail cameras operated from 24–May to 30–September, 2018.

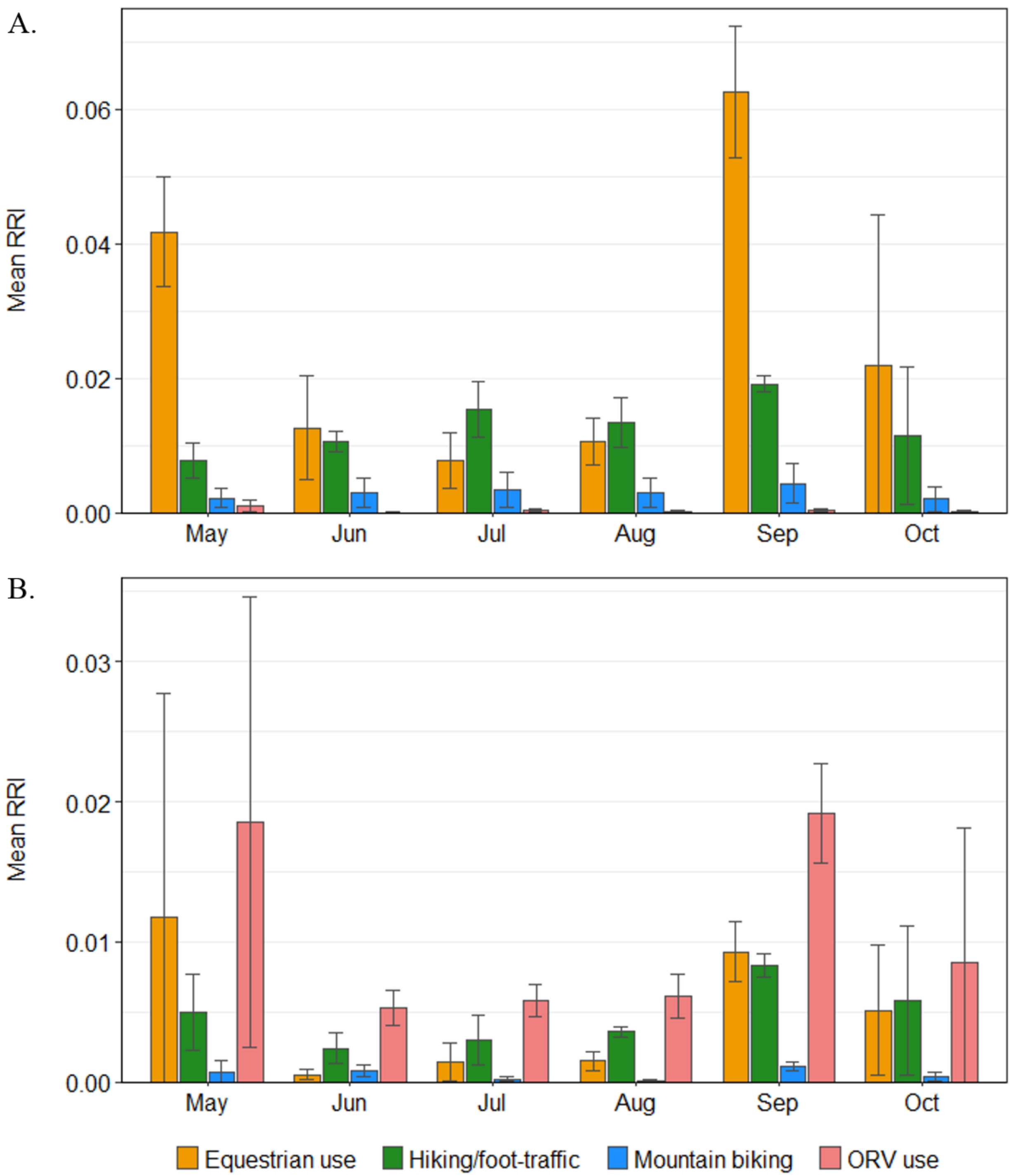


Figure 2.2. Mean relative recreational intensity (i.e. RRI = number of recreation events per camera hour) of equestrian use, hiking/foot-traffic, mountain biking, and ORV use during peak summer–fall recreational periods (i.e., May–October), 2016–2018. Data were captured by remote digital trail cameras in the northern lower peninsula of Michigan: (A) Pigeon River Country State Forest management unit, (B) Atlanta State Forest management unit. Variation depicted by error bars is SD of mean.

Evaluation of recreational intensity by day of week in the PRC

Evaluation of recreational intensity by day of week revealed Saturday, Sunday, and Friday had greater RRIs (Sat = 0.080, Sun = 0.060, Fri = 0.049) and MN6HR ($p < 0.05$; Sat = 1.937, Sun = 1.297, Fri = 1.170) among days of the week during 2016–2018, respectively (Table 2.5). Notably, Saturday had greater RRI and MN6HR ($p < 0.05$) among days of the week for all years and months. Mean RRI's for each day of the week from 2016–2018 had similar distributions among recreation types, with Saturday, Sunday, and Friday having the highest mean intensity for all recreation types, respectively (Figure 2.3). Additionally, we found greater ($p < 0.05$) MN6HR during Friday, Saturday, and Sunday than other days for each recreation type (Table 2.6). Further evaluation for differences among years revealed MN6HR ($p < 0.05$) for Monday, Wednesday, Thursday, and Friday was least during 2018 for equestrian use and hiking/foot-traffic, and all days of the week were least during 2018 for mountain biking.

Evaluation of recreational intensity by time of day in the PRC

Evaluation of recreational intensity by time of day demonstrated that 60.8% (6,941 events) of all recreation events during 2016–2018 occurred between 11:00–16:59, 22.8% (2,596 events) occurred between 17:00–23:00, and 16.4% (1,870 events) occurred between 5:00–10:59 (Table 2.7). Only 5 events (i.e., < 0.001%) occurred from 23:01–4:59 during 2016–2018, which were censored from GLMM analyses. Additionally, the MN6HR was greater ($p < 0.05$) during 11:00–16:59 than 5:00–10:59 and 17:00–23:00 during all years, months, and days. Peak times of day for recreation types in the PRC during 2016–2018 was 10:00–15:59 and 18:00–19:59 for equestrian use (i.e., 75.7% of use), 10:00–16:59 for hiking/foot-traffic (i.e., 73.1% of use), 11:00–17:59 for mountain biking (i.e., 75.6% of use), and 13:00–19:59 for ORV use (77% of use) (Figure 2.4). The majority of events for each recreation type occurred from 11:00–16:59

(Table 2.8), during which the MN6HR was greater ($p < 0.05$) for each type during all years and months.

No differences ($p < 0.05$) were detected for time of day use among years or months for any recreation type. However, there were differences in time of day use among days of the week for each recreation type. For equestrian use, mean time of day use occurred earlier in the day (X^2 = 172.94, df = 6, $p < 0.001$) during days at the beginning of the week (i.e., Monday = 13:00 ± 0:08 [SE], Sunday = 13:06 ± 0:06, Tuesday = 13:30 ± 0:09, Wednesday = 14:00 ± 0:09), and later in the day during days at the end of the week (i.e., Thursday = 14:24 ± 0:07, Friday = 14:24 ± 0:06, Saturday = 14:00 ± 0:05). For hiking/foot-traffic, differences in time of day use among days of the week were primarily between weekend days (i.e., Fri–Sat, Fri–Sun, Sat–Sun) (X^2 = 43.53, df = 6, $p < 0.001$), with mean time of day use occurring latest on Friday (14:12 ± 0:09) and earlier on Saturday (13:30 ± 0:05) and Sunday (13:00 ± 0:06). The mean time of day for mountain biking was earlier (X^2 = 49.93, df = 6, $p < 0.001$) on Saturday (12:54 ± 0:11) than all other days of the week (Monday = 13:18 ± 0:17, Sunday = 14:00 ± 0:13, Tuesday = 14:12 ± 0:26, Wednesday = 14:24 ± 0:23, Thursday = 14:42 ± 0:20, Friday = 14:48 ± 0:17).

Evaluation of recreational intensity during peak days of use in the PRC

Evaluation of the outliers (i.e., n = 25 days) for daily RRI values during 2016-2018 demonstrated: (a) the distribution of days with the greatest RRIs was relatively even among years with 7 occurring in 2016, 9 in 2017, and 9 in 2018; (b) 20 of 25 days with greatest RRIs were during September, including the 6 greatest days; (c) 21 of 25 days with the greatest RRIs were Friday-Sunday; (d) 7 of the 25 days with the greatest RRIs were during holiday weekends (i.e., 2-Memorial Day [i.e., late May], 5-Labor Day [i.e., early September]); and (e) equestrian use accounted for 71.8% (1,927 of 2,684 events) of the recreational activity during days with greatest RRI.

Characteristics of group size for recreation types in the PRC

Mean group sizes for recreation types were 3.14 ± 0.027 (SE) for equestrian use, 2.37 ± 0.044 for hiking/foot-traffic, 1.65 ± 0.041 for mountain biking, and 1.30 ± 0.069 for ORV use during 2016-2018 (Table 2.9). No significant differences in mean group sizes occurred among years or months for hiking/foot-traffic, mountain biking, and ORV use. However, mean group size for equestrian use was greater ($X^2 = 40.61$, df = 2, $p < 0.001$) in 2016 (3.431, ± 0.057) than 2017 (3.013, ± 0.038) and 2018 (3.067, ± 0.046), and greater ($X^2 = 75.37$, df = 5, $p < 0.001$) during May (3.48 ± 0.089) and September (3.22 ± 0.036) (i.e., months of greatest recreational intensity) than June (3.12 ± 0.124), July (3.06 ± 0.093), October (3.05 ± 0.072), and August (2.64 ± 0.053). Additionally, larger group sizes ($X^2 = 62.51$, df = 6, $p < 0.001$) occurred during weekends (i.e., days of greatest recreational intensity; Friday = 3.42 ± 0.081, Saturday = 3.38 ± 0.057, Sunday = 3.10 ± 0.056) than other days of the week (i.e., Thursday = 3.04 ± 0.070, Monday = 2.90 ± 0.072, Tuesday = 2.83 ± 0.063, Wednesday = 2.68 ± 0.066).

While group sizes were relatively small and consistent for each recreation type from 2016-2018, we observed notable outliers (i.e., n = 831 events) in median group size representing substantially larger group sizes for each recreation type (i.e., equestrian use ≥ 8, hiking/foot-traffic ≥ 4, mountain biking ≥ 4). For example, the largest group sizes were 26 for equestrian use, 41 for hiking/foot-traffic, and 15 for mountain biking. The largest groups for hiking/foot-traffic appeared to be organized recreation events for youth accompanied by adults (e.g., school groups, clubs). September had the highest number (n = 312) of such events among all months.

Additionally, Friday through Sunday accounted for 71.81% (n = 596) of such events among days of the week. Lastly, 65% (n = 540) of such events occurred from 11:00-16:59.

Table 2.5. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5-minute period) and recreational intensity (i.e., RRI, MN6HR) by days of the week captured by remote digital trail cameras on public lands within the Pigeon River Country (PRC) and Atlanta (ASF) State Forest Management Units during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

Year/day	Camera hours	PRC events	PRC RRI[1]	PRC MN6HR[2]	ASF events	ASF RRI[1]	ASF MN6HR[2]
2016[a]	65,832	3,105	0.047	0.944	966	0.021	0.229
Monday	9,600	304	0.032	0.842	79	0.012	0.181
Tuesday	9,168	230	0.025	0.450	79	0.013	0.127
Wednesday	9,144	277	0.030	0.588	98	0.016	0.151
Thursday	9,216	410	0.044	0.803	118	0.019	0.136
Friday	9,504	548	0.058	1.393	198	0.031	0.266
Saturday	9,576	746	0.078	1.953	226	0.036	0.596
Sunday	9,624	590	0.061	1.370	168	0.026	0.447
2017[b]	105,504	4,878	0.046	1.084	2,294	0.021	0.264
Monday	14,952	434	0.029	0.816	184	0.012	0.161
Tuesday	15,168	408	0.027	0.635	181	0.012	0.148
Wednesday	15,168	343	0.023	0.558	189	0.012	0.141
Thursday	15,168	508	0.033	0.766	259	0.016	0.240
Friday	15,240	790	0.052	1.467	387	0.024	0.291
Saturday	15,240	1,411	0.093	2.898	691	0.043	0.776
Sunday	14,568	984	0.068	1.873	403	0.026	0.490
2018[c]	92,328	3,429	0.037	0.556	1,774	0.016	0.355
Monday	12,768	329	0.026	0.456	175	0.026	0.295
Tuesday	12,912	342	0.026	0.369	145	0.026	0.228
Wednesday	12,960	293	0.023	0.315	140	0.023	0.200
Thursday	13,344	360	0.027	0.362	211	0.027	0.287
Friday	13,464	532	0.040	0.783	322	0.040	0.392
Saturday	13,488	902	0.067	1.284	443	0.067	0.738
Sunday	13,392	671	0.050	0.849	338	0.050	0.638

Table 2.5. (cont'd)

Total	263,664	11,412	0.043	0.829	5,034	0.019	0.278
Monday	37,320	1,067	0.029	0.679	438	0.012	0.205
Tuesday	37,248	980	0.026	0.473	405	0.011	0.162
Wednesday	37,272	913	0.024	0.469	427	0.011	0.162
Thursday	37,728	1,278	0.034	0.606	588	0.016	0.211
Friday	38,208	1,870	0.049	1.170	907	0.024	0.312
Saturday	38,304	3,059	0.080	1.937	1,360	0.035	0.699
Sunday	37,584	2,245	0.060	1.297	909	0.024	0.519

[1] Number of recreation events per camera hour (i.e., RRI = Rec. events/Camera hours).
[2] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model.
[3] Trail cameras operated from 20–May to 31–October, 2016.
[4] Trail cameras operated from 16–May to 28–October, 2017.
[5] Trail cameras operated from 24–May to 30–September, 2018.

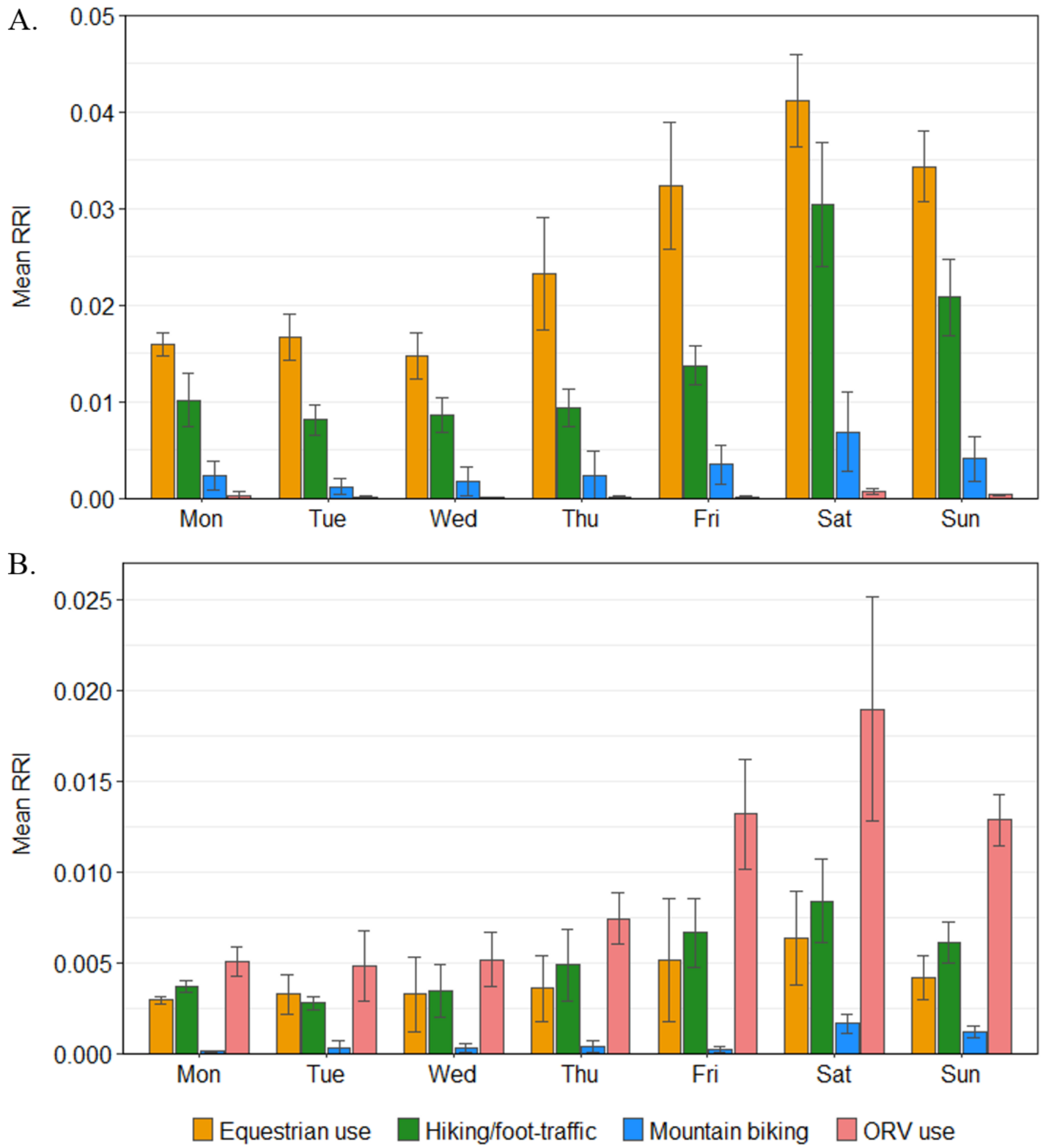


Figure 2.3. Mean relative recreational intensity (i.e. RRI = number of recreation events per camera hour) of equestrian use, hiking/foot-traffic, mountain biking, and ORV use by day of week during peak summer–fall recreational periods (i.e., May–October), 2016–2018. Data were captured by remote digital trail cameras in the northern lower peninsula of Michigan: (A) Pigeon River Country state forest management unit, (B) Atlanta state forest management unit. Variation depicted by error bars is SD of mean.

Table 2.6. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5 minute period) and recreational intensity (i.e., RRI, MN6HR) by days of the week for recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) captured by remote digital trail cameras on public lands within the Pigeon River Country State Forest management unit during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

	Camera	Equestrian use			Hiking/foot-traffic			Mountain-biking			ORV use		
Year/day	hours	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]
2016[a]	65,832	1,785	0.027	2.005	968	0.015	1.056	341	0.005	0.397	11	0.000	
Monday	9,600	151	0.016	1.597	119	0.012	0.911	34	0.004	0.411	0	0.000	
Tuesday	9,168	140	0.015	1.145	73	0.008	0.511	14	0.002	0.156	3	0.000	
Wednesday	9,144	153	0.017	1.314	92	0.010	0.647	31	0.003	0.240	1	0.000	
Thursday	9,216	275	0.030	2.008	86	0.009	0.886	49	0.005	0.291	0	0.000	
Friday	9,504	372	0.039	3.269	125	0.013	1.343	51	0.005	0.616	0	0.000	
Saturday	9,576	371	0.039	3.073	269	0.028	2.367	102	0.011	1.024	4	0.000	
Sunday	9,624	323	0.034	2.684	204	0.021	1.722	60	0.006	0.556	3	0.000	
2017[b]	105,504	2,712	0.026	2.370	1,797	0.017	1.659	338	0.003	0.324	31	0.000	
Monday	14,952	223	0.015	1.592	166	0.011	1.207	41	0.003	0.283	4	0.000	
Tuesday	15,168	232	0.015	1.662	147	0.010	0.987	27	0.002	0.156	2	0.000	
Wednesday	15,168	184	0.012	1.283	138	0.009	0.840	21	0.001	0.161	0	0.000	
Thursday	15,168	318	0.021	1.971	172	0.011	1.155	16	0.001	0.197	2	0.000	
Friday	15,240	486	0.032	3.541	243	0.016	1.933	56	0.004	0.461	5	0.000	
Saturday	15,240	711	0.047	4.692	573	0.038	4.804	114	0.007	1.080	13	0.001	
Sunday	14,568	558	0.038	3.778	358	0.025	3.221	63	0.004	0.540	5	0.000	

Table 2.6. (cont'd)

2018[c]	92,328	2,208	0.024	1.917	1,090	0.012	1.005	99	0.001	0.089	32	0.000
Monday	12,768	221	0.017	1.405	90	0.007	0.798	9	0.001	0.085	9	0.001
Tuesday	12,912	252	0.020	1.525	86	0.007	0.678	3	0.000	0.049	1	0.000
Wednesday	12,960	200	0.015	1.141	86	0.007	0.560	5	0.000	0.049	2	0.000
Thursday	13,344	252	0.019	1.470	99	0.007	0.645	6	0.000	0.050	3	0.000
Friday	13,464	350	0.026	2.984	163	0.012	1.221	19	0.001	0.132	0	0.000
Saturday	13,488	515	0.038	3.281	342	0.025	2.517	34	0.003	0.256	11	0.001
Sunday	13,392	418	0.031	2.704	224	0.017	1.727	23	0.002	0.131	6	0.000
Total	263,664	6,705	0.025	2.088	3,855	0.015	1.208	778	0.003	0.226	74	0.000
Monday	37,320	595	0.016	1.529	375	0.010	0.957	84	0.002	0.214	13	0.000
Tuesday	37,248	624	0.017	1.426	306	0.008	0.699	44	0.001	0.106	6	0.000
Wednesday	37,272	537	0.014	1.244	316	0.008	0.673	57	0.002	0.124	3	0.000
Thursday	37,728	845	0.022	1.799	357	0.009	0.871	71	0.002	0.142	5	0.000
Friday	38,208	1,208	0.032	3.257	531	0.014	1.469	126	0.003	0.335	5	0.000
Saturday	38,304	1,597	0.042	3.617	1,184	0.031	3.059	250	0.007	0.657	28	0.001
Sunday	37,584	1,299	0.035	3.015	786	0.021	2.124	146	0.004	0.340	14	0.000

[1] Number of recreation events per camera hour (i.e., RRI = Rec. events/Camera hours).

[2] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model. Off-road vehicle use (ORV) is prohibited in the PRC and was not included due to insufficient sample size.

[3] Trail cameras operated from 20–May to 31–October, 2016.

[4] Trail cameras operated from 16–May to 28–October, 2017.

[5] Trail cameras operated from 24–May to 30–September, 2018.

Table 2.7. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5 minute period) and recreational intensity (i.e., MN6HR) by time of day (i.e., 3, 6-hour intervals within 5:00–23:00) captured by remote digital trail cameras on public lands within the Pigeon River Country (PRC) State Forest and Atlanta State Forest (ASF) Management Units during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

	PRC		ASF	
Year/time period	events	MN6HR[1]	events	MN6HR[1]
2016[a]	3,102	0.944	964	0.229
05:00–10:59	472	0.549	167	0.119
11:00–16:59	1,931	2.074	424	0.388
17:00–23:00	699	0.739	373	0.261
2017b	4,877	1.084	2,279	0.264
05:00–10:59	775	0.656	348	0.130
11:00–16:59	3,024	2.325	1,135	0.537
17:00–23:00	1,078	0.836	796	0.264
2018c	3,428	0.556	1,767	0.355
05:00–10:59	623	0.363	324	0.209
11:00–16:59	1,986	1.137	814	0.655
17:00–23:00	819	0.416	629	0.327
Total	11,407	0.829	5,010	0.278
05:00–10:59	1,870	0.507	839	0.148
11:00–16:59	6,941	1.763	2,373	0.515
17:00–23:00	2,596	0.636	1,798	0.282

[1] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model.
[3] Trail cameras operated from 20–May to 31–October, 2016.
[4] Trail cameras operated from 16–May to 28–October, 2017.
[5] Trail cameras operated from 24–May to 30–September, 2018.

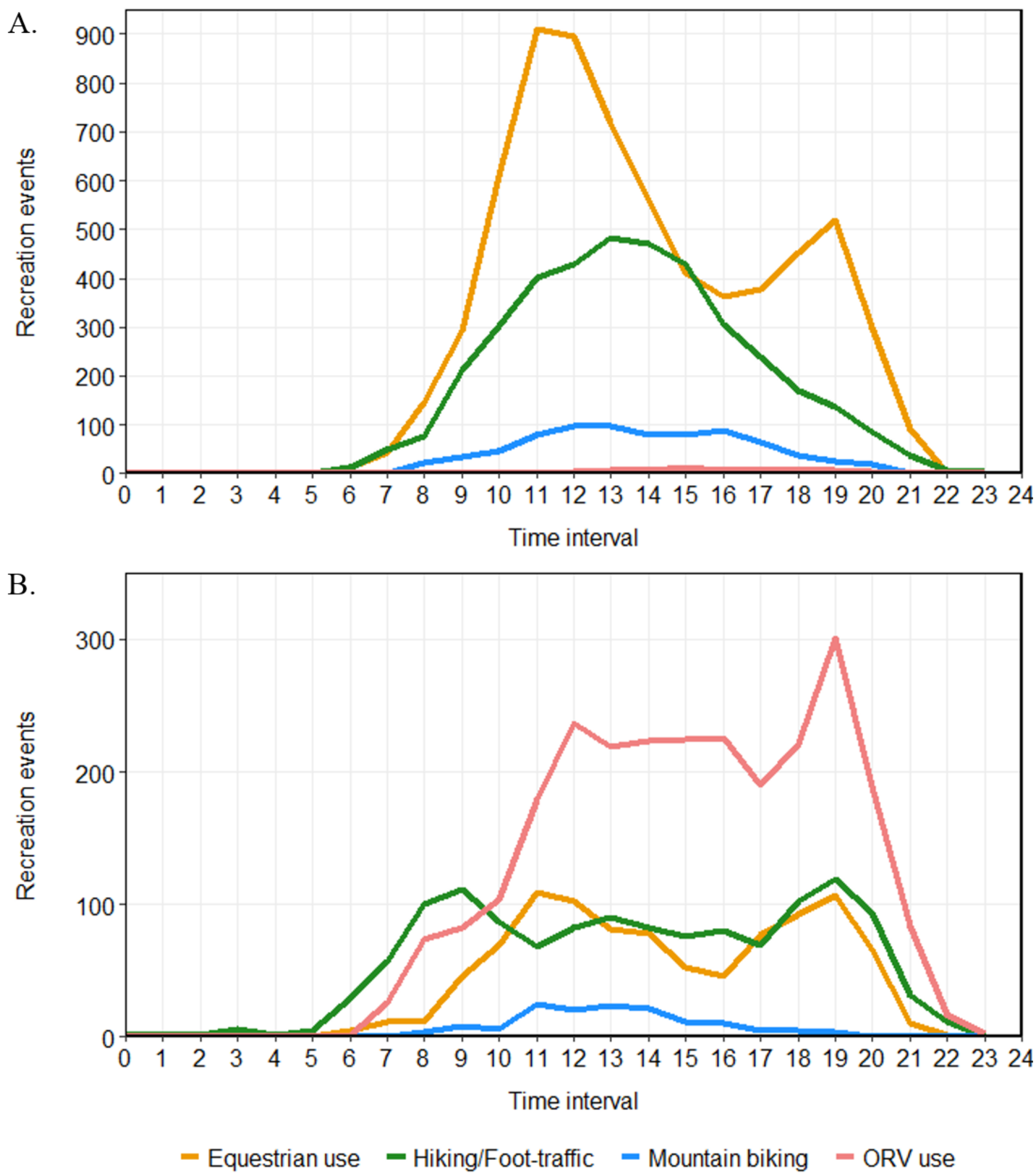


Figure 2.4. Human recreation use (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5 minute period) by hourly time intervals during peak summer–fall recreational periods (i.e., May–October), 2016–2018. Data were captured by remote digital trail cameras in the northern lower peninsula of Michigan: (A) Pigeon River Country State Forest management unit, (B) Atlanta State Forest management unit.

Table 2.8. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5-minute period) and recreational intensity (i.e., MN6HR) by time of day for recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) captured by remote digital trail cameras on public lands within the Pigeon River Country State Forest management unit during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

	Equestrian use		Hiking/foot-traffic		Mountain-biking		ORV use	
Year/time period	events	MN6HR[1]	events	MN6HR[1]	events	MN6HR[1]	events	MN6HR[1]
2016[a]	1,785	2.005	965	1.056	341	0.397	11	
5:00–10:59	265	1.114	161	0.665	45	0.223	1	
11:00–16:59	1,082	3.698	626	2.473	217	0.976	6	
17:00–23:00	438	1.955	178	0.716	79	0.289	4	
2017[a]	2,712	2.370	1,796	1.659	338	0.324	31	
5:00–10:59	438	1.371	292	1.087	45	0.189	0	
11:00–16:59	1,554	4.266	1,209	3.792	235	0.777	26	
17:00–23:00	720	2.275	295	1.108	58	0.232	5	
2018[a]	2,208	1.917	1,089	0.324	99	0.089	32	
5:00–10:59	403	1.197	202	0.711	13	0.056	5	
11:00–16:59	1,221	3.292	683	2.192	72	0.203	10	
17:00–23:00	584	1.788	204	0.652	14	0.062	17	
Total	6,705	2.088	3,850	1.208	778	0.226	74	
5:00–10:59	1,106	1.223	655	0.801	103	0.133	6	
11:00–16:59	3,857	3.731	2,518	2.739	524	0.536	42	
17:00–23:00	1,742	1.996	677	0.803	151	0.161	26	

[1] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model. Off-road vehicle use (ORV) is prohibited in the PRC and was not included due to insufficient sample size.

[a] Trail cameras operated from 20–May to 31–October, 2016; 16–May to 28–October, 2017; 24–May to 30–September, 2018.

Table 2.9. Mean group sizes of trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5 minute period) for recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) captured by remote digital trail cameras on public lands in the Pigeon River Country State Forest management unit during peak summer–fall recreational periods (i.e., May–October), 2016–2018. Trail cameras operated from 20–May to 31–October, 2016; 16–May to 28–October, 2017; 24–May to 30–September, 2018.

Temporal	Equestrian use			Hiking/foot-traffic			Mountain-biking			ORV use		
category	events	mean	SE	events	mean	SE	events	mean	SE	events	mean	SE
Overall	6,705	3.14	0.027	3,855	2.37	0.044	778	1.65	0.041	74	1.30	0.069
2016	1,785	3.43	0.057	968	2.50	0.110	341	1.75	0.076	11	1.00	0.000
2017	2,712	3.01	0.038	1,797	2.34	0.059	338	1.55	0.047	31	1.35	0.989
2018	2,208	3.07	0.047	1,090	2.30	0.072	99	1.64	0.100	32	1.34	0.124
May	551	3.48	0.089	109	2.19	0.141	31	1.74	0.113	12	1.08	0.083
June	560	3.12	0.124	527	2.08	0.066	128	1.93	0.167	1	1.00	0.000
July	387	3.06	0.093	839	2.83	0.014	155	1.57	0.086	25	1.16	0.095
August	616	2.64	0.053	755	2.60	0.011	147	1.62	0.074	11	1.36	0.152
September	3,480	3.22	0.036	1,062	2.15	0.060	219	1.61	0.063	19	1.58	0.192
October	1,111	3.05	0.072	563	2.10	0.078	98	1.51	0.087	6	1.33	0.211
Monday	595	2.90	0.072	375	2.14	0.137	84	1.56	0.080	13	1.23	0.166
Tuesday	624	2.83	0.063	306	2.48	0.178	44	1.48	0.105	6	1.17	0.167
Wednesday	537	2.68	0.066	316	2.47	0.176	57	1.33	0.068	3	1.00	0.000
Thursday	845	3.04	0.071	357	2.36	0.190	71	2.03	0.304	5	1.80	0.583
Friday	1,208	3.42	0.081	531	2.52	0.153	126	1.50	0.076	5	1.00	0.000
Saturday	1,597	3.38	0.057	1,184	2.44	0.064	250	1.70	0.054	28	1.36	0.106
Sunday	1,299	3.10	0.056	786	2.20	0.071	146	1.74	0.096	14	1.29	0.125
5:00–10:59	1,106	3.19	0.067	655	2.21	0.116	103	1.73	0.113	6	1.00	0.000
11:00–16:59	3,857	3.09	0.036	2,518	2.45	0.056	524	1.61	0.041	42	1.38	0.108
17:00–23:00	1,742	3.22	0.049	677	2.25	0.080	151	1.74	0.140	26	0.23	0.084

Relative Intensities, Temporal Characteristics, and Group Sizes of Recreational Users in the ASF

Evaluation of recreational intensity in the ASF

We captured 5,034 recreation events during 266,184 hours of monitoring in the ASF during 2016–2018 (Table 2.2). We censored 21 events due to inability to determine recreation type. The overall RRI was 0.019 and the overall MN6HR was 0.278. Recreation type had the most effect on detection of a recreation event within a 6-hour period followed by month, time of day, day of week, and year (Table 2.3). Off-road vehicle use was the most frequently detected type of trail-based recreation in ASF during 2016–2018 (i.e., RRI = 0.010, MN6HR = 0.988), followed by hiking/foot-traffic (i.e., RRI = 0.005, MN6HR = 0.635), equestrian use (i.e., RRI = 0.004, MN6HR = 0.294), and mountain biking (i.e., RRI = 0.001, MN6HR = 0.032) (Table 2.10).

Evaluation of recreational intensity by year and month in the ASF

Annual total RRI was less during 2018 (0.016) than 2016 (0.021) and 2017 (0.021) (Table 2.2). However, no differences ($p < 0.05$) in MN6HR were detected among years for total trail-based recreational activity or for any recreation types. Off-road vehicle use had the greatest RRI and MN6HR each year, followed by hiking/foot-traffic, equestrian use, and mountain biking, respectively (Table 2.10). Additionally, we found differences ($p < 0.05$) in MN6HR among all recreation types each year. May had the greatest RRI in 2016 (0.072) and September had the greatest RRIs in 2017 (0.038) and 2018 (0.038) (Table 2.2). However, there were only 432 camera hours for 3 days (i.e., 29–31) of a holiday weekend in the ASF during May 2016, which likely inflated the RRI. Additionally, September had the second greatest RRI in 2016 (0.037) which was consistent with 2017 and 2018 (Table 2.2). Moreover, the MN6HR was greater (p <

0.05) in September (0.814) than all other months (May = 0.338, June = 0.156, July = 0.219, August = 0.177) during 2016–2018.

Off-road vehicle use had the greatest mean RRIs among recreation types during all months (Figure 2.10). While hiking/foot-traffic had greater monthly mean RRIs than equestrian use from June through August, and October, equestrian use had greater mean RRIs during May and September. Mountain biking had the least mean RRIs each month. We observed similar trends for total monthly MN6HR with ORV use being greatest ($p < 0.05$) and mountain biking being least ($p < 0.05$) for all months (Table 2.10). While hiking/foot-traffic had greater total monthly MN6HR than equestrian use during all months except for September, we only found differences ($p < 0.05$) during July and August. We found similar trends among months for each recreation type, with September having the greatest mean RRIs for hiking/foot-traffic (0.008, SD = 0.0008), mountain biking (0.001, SD = 0.0003), and ORV use (0.019, SD = 0.004) during 2016–2018 (Figure 2.2). For equestrian use, May had the greatest mean RRI (0.012, SD = 0.016) among months during 2016–2018, however, the RRI for May 2016 was likely inflated due to the short monitoring period and timing. As a result, the SD (0.016) was larger than the estimated mean RRI (0.012) for equestrian use in May 2016. September had the second greatest mean RRI (0.009, SD = 0.002) for equestrian use during 2016–2018, which is consistent with the trend of greater recreational use during September for other types. Additionally, the MN6HR was significantly higher during September for equestrian use (1.507), hiking/foot-traffic (1.364), and ORV use (2.630) during 2016–2018 (Table 2.10).

Evaluation of recreational intensity by day of week in the ASF

Evaluation of recreational intensity by day of week revealed Saturday, Sunday, and Friday had the greatest total RRIs (Table 2.5) and total MN6HR (Sat = 0.699, Sun = 0.519, Fri = 0.312) during 2016–2018, respectively. Saturday had the greatest RRI among days of the week for all years and months. Additionally, the total MN6HR for Saturday was greater ($p < 0.05$) than weekdays during all years and months, with only Sunday having no difference ($p < 0.05$) from Saturday for 2016, 2018, and May, July, and August during 2016–2018.

Mean RRI's for each day of the week during 2016–2018 had similar patterns among equestrian use, hiking/foot-traffic, and ORV use, with each having the greatest daily RRIs on Saturday, Friday, and Sunday, respectively (Figure 2.3). Mountain biking had its greatest daily RRIs on Saturday, Sunday, and Thursday, respectively. Additionally, all recreation types had greater ($p < 0.05$) MN6HR on Saturday than all other days except for Sunday (Table 2.11).

Evaluation of recreational intensity by time of day in the ASF

Evaluation of recreational intensity by time of day revealed that 47.1% of all events (2,373) occurred between 11:00–16:59, 35.7% (i.e., 1,798 events) occurred between 17:00–23:00, and 16.7% (i.e., 839 events) between 5:00–10:59 (Table 2.7). Notably, we censored 24 events (i.e., < 0.005%) from our GLMM analysis that occurred from 23:01–4:59, during 2016–2018. Additionally, the MN6HR was greater ($p < 0.05$) between 11:00–16:59 from 5:00–10:59 and 17:00–23:00 during all study years, months, and days of week. Peak times of day for recreation types during 2016–2018 were 10:00–14:59 and 17:00–20:59 for equestrian use (i.e., 80.7% of use), 8:00–10:59, 12:00–16:59, and 18:00–20:59 for hiking/foot-traffic (i.e., 78.2% of use), 11:00–16:59 for mountain biking (i.e., 77.6% of use), and 12:00–19:59 for ORV use (70.6% of use) (Figure 2.4). Similar to the PRC, the MN6HR was greater ($p < 0.05$) during 11:00–16:59 for each recreation type during all study years and months (Table 2.12).

No differences ($p < 0.05$) were detected for time of day use among years for equestrian use and hiking/foot-traffic. For mountain biking, mean time of day use was later ($X^2 = 12.23$, df = 2, p = 0.002) during 2017 (14:06 ± 0:24 [SE]) than 2016 (12:48 ± 0:26) and 2018 (12:24 ± 0:16). For ORV use, mean time of day use was later ($X^2 = 8.39$, df = 2, p = 0.015) during 2016 (15:30 ± 0:11) than 2017 (15:06 ± 0:06) and 2018 (14:54 ± 0:08). We found differences in time of day use among study months for equestrian use, hiking/foot-traffic, and ORV use. For equestrian use, mean time of day use was earliest ($X^2 = 17.98$, df = 5, p = 0.003) during July (12:48 ± 0:34) and latest during June (15:24 ± 0:50), while being relatively consistent (i.e., means were 14:00–14:48) among other study months. For hiking/foot-traffic, mean time of day use was earlier ($X^2 = 47.68$, df = 5, p < 0.001) during May (12:42 ± 0:25), October (13:12 ± 0:12), and September (13:00 ± 0:16) than other study months (i.e., July = 14:12 ± 0:22, August = 14:54 ± 0:18, June = 15:06 ± 0:21). For ORV use, mean time of day use was earliest ($X^2 = 49.07$, df = 5, p < 0.001) during October (14:24 ± 0:09), May (14:48 ± 0:21), and September (14:54 ± 0:06), and latest during July (15:54 ± 0:11), June (15:42 ± 0:14), and August (15:24 ± 0:12). Additionally, we found an earlier mean time of day use ($X^2 = 46.99$, df = 6, p < 0.001) for ORV use during Sunday (14:18 ± 0:10) from all other days of the week (i.e., means were 15:18–15:54).

Evaluation of recreational intensity during peak days of use in the ASF

Evaluation of the outliers (i.e., n = 41 days) for daily RRI values during 2016–2018 demonstrated: (a) there were more days (20) with the greatest RRIs during 2017 than 2016 (15) and 2018 (6); (b) 21 of 41 days with greatest RRIs were during September; (c) 34 of 41 days with the greatest RRIs occurred from Friday–Sunday; (d) 15 of the 41 days with the greatest RRIs were during holiday weekends (i.e., 4-Memorial Day, 2-Independence Day [4th of July], 5-Labor Day); and (e) ORV use accounted for 52.9% (937 of 1,770 events) of recreational activity during days with greatest RRIs.

Table 2.10. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5-minute period) and recreational intensity (i.e., RRI, MN6HR) for recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) captured by remote digital trail cameras on public lands within the Atlanta State Forest management unit during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

	Camera	Equestrian use			Hiking/foot-traffic			Mountain-biking			ORV use		
Year/month	hours	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]
2016	44,472	264	0.006	0.281	265	0.006	0.433	33	0.001	0.032	404	0.009	0.710
May[3]	432	13	0.030	1.012	2	0.005	0.930	0	0.000	0.100	16	0.037	1.579
June	6,816	4	0.001	0.107	10	0.001	0.374	9	0.001	0.079	45	0.007	0.585
July	7,440	22	0.003	0.180	14	0.002	0.431	0	0.000	0.028	39	0.005	0.700
August	7,824	11	0.001	0.152	30	0.004	0.263	1	0.000	0.005	49	0.006	0.357
September	10,800	112	0.010	0.596	92	0.009	0.384	16	0.001	0.033	180	0.017	0.781
October[3]	11,160	102	0.009		117	0.010		7	0.001		75	0.007	
2017	109,872	324	0.003	0.219	586	0.005	0.755	50	0.000	0.025	1,334	0.012	1.186
May[4]	5,064	20	0.004	0.219	40	0.008	0.452	2	0.000	0.022	42	0.008	0.734
June	19,632	3	0.000	0.023	71	0.004	0.177	10	0.001	0.017	104	0.005	0.265
July	22,440	15	0.001	0.141	114	0.005	0.756	6	0.000	0.021	160	0.007	1.176
August	22,320	20	0.001	0.351	71	0.003	1.365	3	0.000	0.011	169	0.008	1.774
September	21,600	148	0.007	2.051	159	0.007	2.968	20	0.001	0.113	503	0.023	5.776
October[4]	18,816	118	0.006		131	0.007		9	0.000		356	0.019	
2018	111,840	381	0.003	0.414	459	0.004	0.783	64	0.001	0.043	870	0.008	1.146
May[5]	4,392	5	0.001	0.484	11	0.003	0.547	7	0.002	0.043	45	0.010	0.828
June	27,000	23	0.001	0.138	59	0.002	0.591	20	0.001	0.092	109	0.004	0.824
July	27,120	17	0.001	0.204	55	0.002	0.601	9	0.000	0.028	139	0.005	0.870
August	27,432	60	0.002	0.320	102	0.004	0.682	1	0.000	0.009	122	0.004	0.825
September	25,896	276	0.011	2.803	232	0.009	2.226	27	0.001	0.142	455	0.018	4.034

Table 2.10. (cont'd)

Total	266,184	969	0.004	0.294	1,310	0.005	0.635	147	0.001	0.032	2,608	0.010	0.988
May[3–5]	9,888	38	0.004	0.475	53	0.005	0.613	9	0.001	0.045	103	0.010	0.986
June	53,448	30	0.001	0.069	140	0.003	0.340	39	0.001	0.049	258	0.005	0.503
July	57,000	54	0.001	0.173	183	0.003	0.581	15	0.000	0.026	338	0.006	0.895
August	57,576	91	0.002	0.257	203	0.004	0.626	5	0.000	0.008	340	0.006	0.805
September	58,296	536	0.009	1.507	483	0.008	1.364	63	0.001	0.081	1,138	0.020	2.630
October[3–5]	29,976	220	0.007		248	0.008		16	0.001		431	0.014	

[1] Number of recreation events per camera hour (i.e., RRI = Rec. events/Camera hours).
[2] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model.
[3] Trail cameras operated from 20–May to 31–October, 2016.
[4] Trail cameras operated from 16–May to 28–October, 2017.
[5] Trail cameras operated from 24–May to 30–September, 2018.

Table 2.11. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5 minute period) and recreational intensity (i.e., RRI, MN6HR) by days of the week for recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) captured by remote digital trail cameras on public lands within the Atlanta State Forest management unit during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

	Camera	Equestrian use			Hiking/foot-traffic			Mountain-biking			ORV use		
Year/day	hours	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]	events	RRI[1]	MN6HR[2]
2016[a]	44,472	264	0.006	0.281	265	0.006	0.433	33	0.001	0.032	404	0.009	0.710
Monday	6,576	19	0.003	0.333	25	0.004	0.411	1	0.000	0.013	34	0.005	0.579
Tuesday	6,216	24	0.004	0.224	19	0.003	0.235	5	0.001	0.014	31	0.005	0.351
Wednesday	6,216	35	0.006	0.197	32	0.005	0.290	3	0.000	0.019	28	0.005	0.476
Thursday	6,216	34	0.005	0.142	42	0.007	0.253	0	0.000	0.026	42	0.007	0.362
Friday	6,336	57	0.009	0.342	56	0.009	0.625	0	0.000	0.021	85	0.013	1.097
Saturday	6,360	59	0.009	0.517	53	0.008	0.916	14	0.002	0.149	100	0.016	1.790
Sunday	6,552	36	0.005	0.378	38	0.006	0.702	10	0.002	0.114	84	0.013	1.319
2017[b]	109,872	324	0.003	0.219	586	0.005	0.755	50	0.000	0.025	1,334	0.012	1.186
Monday	15,480	43	0.003	0.201	51	0.003	0.556	1	0.000	0.008	89	0.006	0.751
Tuesday	15,720	31	0.002	0.176	45	0.003	0.413	1	0.000	0.011	104	0.007	0.592
Wednesday	15,720	37	0.002	0.124	43	0.003	0.409	1	0.000	0.012	108	0.007	0.643
Thursday	15,720	30	0.002	0.170	79	0.005	0.678	8	0.001	0.031	142	0.009	0.929
Friday	15,936	41	0.003	0.253	85	0.005	1.038	5	0.000	0.016	256	0.016	1.747
Saturday	16,008	84	0.005	0.455	171	0.011	1.808	19	0.001	0.130	417	0.026	3.386
Sunday	15,288	58	0.004	0.280	112	0.007	1.167	15	0.001	0.084	218	0.014	2.100

Table 2.11. (cont'd)

2018[c]	111,840	381	0.003	0.414	459	0.004	0.783	64	0.001	0.043	870	0.008	1.146
Monday	15,408	49	0.004	0.516	60	0.004	0.783	2	0.000	0.019	64	0.004	0.985
Tuesday	15,888	62	0.002	0.381	38	0.002	0.491	1	0.000	0.022	44	0.003	0.655
Wednesday	15,912	29	0.003	0.248	40	0.003	0.449	6	0.000	0.022	65	0.004	0.656
Thursday	15,888	53	0.003	0.286	45	0.003	0.627	10	0.001	0.047	103	0.006	0.800
Friday	15,224	62	0.006	0.479	93	0.006	1.076	4	0.000	0.027	163	0.010	1.686
Saturday	16,272	74	0.006	0.609	99	0.006	1.327	25	0.002	0.159	245	0.015	2.313
Sunday	15,248	52	0.005	0.512	84	0.005	1.171	16	0.001	0.141	186	0.011	1.962
Total	266,184	969	0.004	0.294	1,310	0.005	0.635	147	0.001	0.032	2,608	0.010	0.988
Monday	37,464	111	0.003	0.326	136	0.004	0.564	4	0.000	0.013	187	0.005	0.754
Tuesday	37,824	117	0.003	0.247	102	0.003	0.362	7	0.000	0.015	179	0.005	0.514
Wednesday	37,848	101	0.003	0.182	115	0.003	0.376	10	0.000	0.017	201	0.005	0.585
Thursday	37,824	117	0.003	0.191	166	0.004	0.475	18	0.000	0.034	287	0.008	0.646
Friday	38,496	160	0.004	0.346	234	0.006	0.887	9	0.000	0.021	504	0.013	1.478
Saturday	38,640	217	0.006	0.523	323	0.008	1.300	58	0.002	0.145	762	0.020	2.412
Sunday	38,088	146	0.004	0.379	234	0.006	0.986	41	0.001	0.111	488	0.013	1.758

[1] Number of recreation events per camera hour (i.e., RRI = Rec. events/Camera hours).
[2] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model.
[3] Trail cameras operated from 20–May to 31–October, 2016.
[4] Trail cameras operated from 16–May to 28–October, 2017.
[5] Trail cameras operated from 24–May to 30–September, 2018.

Table 2.12. Trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5 minute period) and recreational intensity (i.e., MN6HR) by time of day (i.e., 3, 6-hour intervals within 5:00–23:00) for recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) captured by remote digital trail cameras on public lands within the Atlanta State Forest management unit during peak summer–fall recreational periods (i.e., May–October), 2016–2018.

	Equestrian use		Hiking/foot-traffic		Mountain-biking		ORV use	
Year/time period	events	MN6HR[1]	events	MN6HR[1]	events	MN6HR[1]	events	MN6HR[1]
2016[a]	263	0.281	265	0.433	33	0.032	403	0.710
5:00–10:59	42	0.124	79	0.353	4	0.018	42	0.259
11:00–16:59	125	0.404	80	0.438	26	0.114	193	1.133
17:00–23:00	96	0.444	106	0.525	3	0.016	168	1.219
2017[a]	324	0.219	576	0.755	50	0.025	1,329	1.186
5:00–10:59	40	0.091	170	0.581	4	0.013	134	0.408
11:00–16:59	184	0.377	235	0.917	37	0.105	679	2.274
17:00–23:00	100	0.304	171	0.807	9	0.011	516	1.796
2018[a]	381	0.414	455	0.783	64	0.043	867	1.146
5:00–10:59	62	0.207	140	0.723	10	0.027	112	0.473
11:00–16:59	161	0.647	165	0.863	51	0.165	437	1.994
17:00–23:00	158	0.529	150	0.769	3	0.018	318	1.594
Total	968	0.294	1,296	0.635	147	0.032	2,599	0.988
5:00–10:59	144	0.133	389	0.529	18	0.018	288	0.368
11:00–16:59	470	0.462	480	0.702	114	0.126	1,309	1.725
17:00–23:00	354	0.415	427	0.688	15	0.015	1,002	1.517

[1] Mean number of recreation events during all 6-hour intervals for a given time period. Values were obtained by back-transformation of estimated logmean number of events using a generalized linear mixed model.
[a] Trail cameras operated from 20–May to 31–October, 2016; 16–May to 28–October, 2017; 24–May to 30–September, 2018.

Characteristics of group size for recreation types in the ASF

Mean group sizes for recreation types were 2.83 ± 0.070 (SE) for equestrian use, 1.91 ± 0.036 for hiking/foot-traffic, 1.47 ± 0.090 for mountain biking, and 1.28 ± 0.014 for ORV use during 2016–2018 (Table 2.13). No differences ($p < 0.05$) were detected in mean group sizes among years or months for any recreation type. However, mean group size was greatest on Saturday for equestrian use (3.55 ± 0.211; $X^2 = 48.71$, df = 6, $p < 0.001$), hiking/foot traffic (2.25 ± 0.092; $X^2 = 46.99$, df = 6, $p < 0.001$), and ORV use (1.38 ± 0.032; $X^2 = 46.99$, df = 6, $p < 0.001$). Additionally, mean group size was greater on Friday, Saturday, and Sunday than other days for equestrian use, hiking/foot-traffic, and mountain biking (Table 2.13). Similar to the PRC, we observed notable outliers (n = 791 events) in median group size representing substantially larger group sizes for each recreation type (i.e., equestrian use ≥ 5, hiking/foot-traffic ≥ 4, mountain biking ≥ 2, ORV use ≥ 2). The largest group sizes for each recreation type were 22 for equestrian use, 12 for hiking/foot-traffic, 8 for mountain biking, and 13 for ORV use. September had the highest number (n = 362) of such events among months. Additionally, Friday through Sunday accounted for 73.7% (n = 583) of such events among days of the week. Lastly, 52.7% (n = 417) of such events occurred from 11:00–16:59.

Table 2.13. Mean group sizes of trail-based recreation events (i.e., any number of individuals of the same recreation type passing by a camera in the same direction within a 5 minute period) for recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) captured by remote digital trail cameras on public lands in the Atlanta State Forest management unit during peak summer–fall recreational periods (i.e., May–October), 2016–2018. Trail cameras operated from 20–May to 31–October, 2016; 16–May to 28–October, 2017; 24–May to 30–September, 2018.

Temporal	Equestrian use			Hiking/foot-traffic			Mountain-biking			ORV use		
category	events	mean	SE	events	mean	SE	events	mean	SE	events	mean	SE
Overall	969	2.83	0.070	1,310	1.91	0.036	147	1.47	0.090	2,608	1.28	0.014
2016[a]	264	2.92	0.139	265	1.92	0.077	33	1.82	0.248	404	1.32	0.046
2017[b]	324	2.76	0.127	586	1.88	0.051	50	1.24	0.079	1,334	1.30	0.018
2018[c]	381	2.83	0.102	459	1.94	0.067	64	1.47	0.146	870	1.24	0.023
May	38	2.97	0.265	53	1.91	0.146	9	1.44	0.242	103	1.27	0.065
June	30	2.40	0.163	140	1.80	0.120	39	1.62	0.225	258	1.19	0.031
July	54	2.48	0.154	183	2.19	0.115	15	1.07	0.067	338	1.48	0.061
August	91	2.66	0.135	203	2.01	0.103	5	1.00	0.000	340	1.21	0.028
September	536	2.87	0.086	483	1.89	0.056	63	1.56	0.143	1,138	1.27	0.020
October	220	2.93	0.208	248	1.74	0.068	16	1.31	0.176	431	1.27	0.028
Monday	111	2.35	0.093	136	1.57	0.074	4	1.00	0.000	187	1.31	0.052
Tuesday	117	2.38	0.108	102	1.79	0.134	7	1.00	0.000	179	1.10	0.024
Wednesday	101	2.23	0.105	115	1.69	0.077	10	1.00	0.000	201	1.11	0.023
Thursday	117	2.18	0.095	166	1.66	0.065	18	1.17	0.090	287	1.36	0.044
Friday	160	3.41	0.223	234	1.91	0.078	9	1.22	0.222	504	1.23	0.029
Saturday	217	3.55	0.211	323	2.25	0.092	58	1.93	0.201	762	1.38	0.032
Sunday	146	2.80	0.142	234	1.98	0.094	41	1.24	0.084	488	1.25	0.027
5:00–10:59	144	2.45	0.163	389	1.67	0.051	18	3.00	0.485	288	1.19	0.030
11:00–16:59	470	2.87	0.104	480	1.86	0.056	114	1.19	0.056	1,309	1.33	0.022
17:00–23:00	354	2.94	0.113	427	2.20	0.076	15	1.73	0.206	1,002	1.23	0.020

Comparisons between the PRC and ASF

Overall RRI was greater for the PRC (0.043) than ASF (0.019), with more than twice the number of events (11,412 PRC, 5,034 ASF) captured during fewer overall camera hours (263,664 PRC, 266,184 ASF) (Table 2.2). Despite differences in recreation intensity between study regions, we found similar patterns for recreational intensity by year, month, day of week, and time of day in both study regions. Both study regions had similar RRI during 2016 and 2017, and lower RRI in 2018 (Table 2.2). September, October, and May had the highest overall RRIs by month for both study regions, respectively (Table 2.2). Saturday, Sunday, and Friday had the highest overall RRIs by day of week for both study regions, respectively (Table 2.4). The majority of events occurred between 11:00–16:59 in both study regions (Table 2.7). Additionally, temporal patterns for peak days of use were relatively similar between regions with September and weekend days accounting for most of peak days during the study.

While recreational intensity was similar between regions in temporal patterns of annual, monthly, day of week, time of day, and peak days of use, we found differences in which recreation types were most prominent between regions. Equestrian use accounted for the most (58.8%) recreation events in the PRC, while ORV use accounted for the most (51.8%) events in the ASF. Notably, equestrian use only accounted for 19.2% of events in the ASF, while ORV use predictably accounted for < 1% of events in the PRC due to being prohibited. Additionally, ORV use was the only recreation type to have greater RRIs in the ASF than the PRC.

Our study regions also differed by which variables had the most effect on detection of a recreation event. Recreation type, month, and time of day had the most effect on detection of a recreation event within a 6-hour period for both regions, not respectively (Table 2.3). However, time of day had the most effect for the PRC, while recreation type had the most effect for ASF.

In both regions, day of week and year had the least effect on detection of a recreation event within a 6-hour period. Lastly, mean group sizes and the largest group sizes for each recreation type besides ORV use were smaller in the ASF than the PRC (Tables 2.9 and 2.13).

DISCUSSION

Our study demonstrated consistent summer-fall use of two public land areas for trail-based recreational activities in the Michigan elk range during 2016-2018. Although variation in recreational intensity among study months, days of week, and time of day were expected based on previous literature (Ladle et al. 2017, Longshore et al. 2013, Reilly et al. 2017), we did not expect to find differences among study years. However, we believe our findings of less recreational intensity during 2018 may be due in part to greater daily temperatures. For example, 2018 had greater mean daily high temperatures for May-August, which may explain the decreased recreational intensity in both study regions during all months besides September in 2018 (NOAA 2020). Notably, 2018 had more days of ≥ 26.7 ˚C (60 days) and ≥ 32.2 ˚C (13 days) than 2016 (i.e., ≥ 26.7 ˚C = 50 days, ≥ 32.2 ˚C = 7 days) and 2017 (i.e., ≥ 26.7 ˚C = 38 days, ≥ 32.2 ˚C = 3 days).

Our findings of greater recreational intensities in May and September each year in each region may be due in part to lower daily high temperatures. Mean daily high temperatures for our study area were lower in May and September than June-August each year (NOAA 2020). While September had the highest recreational intensities among months for all trail-based recreation types, the differences among months was most prominent for equestrian use. For example, the RRI for equestrian use in September was 9 times greater than July in both regions during 2016-2018, while only being 1.3-3.3 times greater for other recreation types. We believe the disparity in recreational intensity between September and other months for equestrian use is likely due in part to preferences for riding during cooler temperatures. A national online poll that surveyed equestrian users for preference of riding season showed that 57.2% of 764 respondents preferred riding in fall, 22% spring, 15.2% summer, and 5.6% winter (Whittle 2017). Approximately 21%

of the respondents commented their primary reasons for preferring fall riding were cooler temperatures, fall colors, and fewer insects. Moreover, the University of Minnesota Extension recommends avoiding riding horses during periods when the combined air temperature (˚F) and relative humidity is > 150 due to reduced cooling efficiency and potential for overheating (Martinson et al. 2020). Evaluation of climatological data during our study showed that 55.4% of days during June-August had periods when the combined air temperature (˚F) and relative humidity was > 150, while only 30.6% of days with such conditions occurred during May and September (NOAA 2020). Although hotter temperatures (i.e., > 32 ˚C) have been found to affect recreational patterns for hiking and bicycling, responses are typically to change to earlier or later times of the day when temperatures are cooler (Li and Lin 2012, Chan and Whichman, 2020).

Greater recreational intensity in May and September may also be due to annual US federal holiday weekends each month (i.e., Memorial Day, a Monday in May; Labor Day, a Monday in September). Our findings of greater recreational intensity during Memorial Day and Labor Day weekends (i.e., 25% of our highest daily RRI values) are consistent with previous research identifying greater visitor numbers in natural areas during holidays (Dwyer 1988, Remacha et al. 2016). Further evaluation of mean RRI values during Memorial Day and Labor Day weekend days (i.e., Friday–Monday) showed RRIs were 2.4 times greater than other weekends. Hence, we believe the greater observed recreational intensities during May and September were primarily due to the combination of lower daily high temperatures and occurrences of Memorial Day and Labor Day holiday weekends.

Our findings of greater recreational intensity during weekends and mid-day (i.e., 11:00–17:00) for all recreation types in both regions are similar to previous research on public lands (Ladle et al. 2017, Longshore et al. 2013). Our findings of earlier (i.e., 2:36) time of day use for equestrian users during July from June in the ASF may be due to greater mean high temperatures. Evaluation of average monthly high temperatures during 2016-2018 showed July had a 2.8 $^{\circ}$C greater mean high temperature than June. Equestrian users may have modified riding times for earlier in the day to avoid hotter temperatures. Our findings of earlier use for all recreation types during weekend days is likely due to increased use during weekends. Increased presence of recreational users that are camping during weekends may explain our findings of later use on days of arrival (i.e., Thursday, Friday) and earlier use on days of departure (i.e., Saturday–Tuesday). Our findings of later use for ORV users may be attributed to headlights and speed of travel for returning to camping sites.

The differences we documented in recreational intensity, type of use, and group size between the PRC and ASF may be related to availability of recreational trails and amenities. Previous research has suggested that trail attributes (e.g., trail markers, loops, lengths > 24 km) and site amenities (e.g., water sources, camping sites) may contribute to increases in annual visits by equestrian users $\geq$ 4 visits per available attribute or amenity (Blackwell et al. 2009). The PRC had greater recreational intensity than ASF during all months and years while providing 2.5 times more designated recreational trails per km^2 (i.e., PRC = 0.46 km/km^2, ASF = 0.18 km/km^2) and designated camping and horse camping sites that offer numerous amenities. Although equestrian use was the most frequently detected type of trail-based recreation in the PRC (i.e., 58.7% of events) given our objectives, it only accounted for 19.2% of events in the ASF. We believe the disparity in intensity of equestrian use between regions is primarily due to lack of the above-mentioned amenities and designated trails in the ASF. The PRC has 69.34 km of designated equestrian trails while the ASF has none. Equestrian users have 6 equestrian campgrounds in the PRC, of which 5 have direct connections to designated trails. The primary horse campground in the PRC (i.e., Elk Hill Trail Campground) provides amenities for first-come, first-served camping and reserved group camping which accommodates up to 5 equestrian groups and has a maximum capacity of 100 individuals. The PRC also provides 6 rustic campgrounds with amenities that provide easy access for numerous recreational opportunities, including 79.77 km of trails designated to bicycling and hiking, while the ASF has none. Hence, the PRC provides numerous attributes that may be appealing to some recreational users and that are not available in the ASF.

In contrast, the absence of designated trails and amenities in the ASF may be appealing to different users who prefer fewer or no restrictions (e.g., off-trail riding, open camping). For example, in-person communications with equestrian users in the ASF revealed a preference for off-trail riding and discovering new areas to camp. Conversely, in-person communications with equestrian users in the PRC revealed a preference for riding in familiar areas that were close to horse camps that provided amenities for large groups. Our findings of larger mean group size for equestrian users in the PRC (3.14 ± 0.027) from ASF (2.83 ± 0.070) may support observed user preferences for allowance of larger equestrian groups in the PRC. The presence of relatively larger hiking/foot-traffic group sizes (e.g., 41 individuals) of adult-led youth groups only occurring in the PRC are likely due to the presence of marked designated trails for hiking. Marked designated trails may provide security for recreational users, especially when leading large groups or when hikers are unfamiliar with large tracts of public land.

Greater equestrian use in the PRC than the ASF may also be due to avoidance of areas with ORVs and mountain biking. Others have reported user conflicts between motorized and non-motorized forms of recreation (Adams and McCool 2009, Shilling et al. 2012, Vaske et al. 2007). An online survey used by Shilling et al. (2012) to determine trail user preferences and experiences in the Tahoe National Forest reported 63% of non-motorized recreational users (i.e., equestrian users, hikers, mountain bikers) that wrote additional comments reported conflicts with motorized forms (e.g., quads, motorcycles) of recreation. Approximately 54% of equestrian users and 27% of hikers reported opposition against multiple-use trails (Shilling et al. 2012). Personal communications with equestrian users in the PRC indicated preferences for avoiding areas allowing ORVs and mountain bikes, primarily due to avoidance of disturbances to horses caused by loud and faster moving recreational users.

In addition to user preferences based on recreational restrictions, designated trails, and amenities within each forest, differences in recreational intensity may be related to the proximity of Interstate-75 and 2 communities (i.e., Gaylord, MI and Indian River, MI) that provide access to external amenities (e.g., lodging, restaurants, consumer goods) along the interstate. Previous research documented that presence of interstate highways increases economic activity in counties they pass through while causing a decrease in adjacent counties (Chandra and Thompson 2000). Additional research has documented a decreased likelihood of visitation to protected nature conservation sites with distance from local housing (Neuvonen et al. 2010, Rossi et al. 2015, Weitowitz et al. 2019). Approximately 97% of the PRC is within Otsego and Cheboygan counties which have a combined population of 50,100, and incorporate Interstate-75, the city of Gaylord (i.e., approximately 3,700 residents), and the community of Indian River (i.e., approximately 1,960 residents) that provide goods and services such as lodging and dining. Notably, the western border of the PRC can be reached from the closest Interstate-75 off-ramp (i.e., exit 290) with a 5 to 10-minute (i.e., 6.4 km) drive using the only paved road (i.e., East Sturgeon Valley Road) within the PRC. Additionally, there is signage located 0.5 km from the Interstate off-ramp reading “Sturgeon Valley Road gateway to Pigeon River Country” to direct visitors. Conversely, approximately 88% of the ASF within the elk range is located within Montmorency County which has an estimated population of 9,265 and its largest communities are Lewiston (i.e., approximately 1,400 residents) and Atlanta (i.e., approximately 760 residents). Atlanta is only 1.3 km from the southern edge of the ASF, but only provides two motels for lodging and few options for dining and goods. The shortest drive to reach the ASF from the closest Interstate-75 off-ramp (i.e., exit 282) takes approximately 30 minutes (i.e., 32.5 km) along Highway-32 and several county roads, which have no signs directing visitors or advertising the ASF (C. Stevens, MDNR, personal communication). The close proximity of the PRC to the only interstate through the northern half of the lower peninsula of Michigan and nearby population centers may be contributing factors for greater visitor use than the ASF.

Differences in recreational intensity between the two state forests may also be attributed to the degree of familiarity users had and differences in tourism promotion. Previous research documented increased use and greater preferences for recreation sites that were highly promoted, provided more tourism infrastructure, and were perceived as being popular (Hallmann et al. 2014, Schägner et al. 2016, Schirpke et al. 2018). Additionally, Neuvonen et al. (2010) documented that older national parks in Finland had greater visitor numbers than newer parks, which was attributed to greater public awareness. Awareness and interest in the PRC has increased since the early 20th century following the introduction of 7 elk in 1918, elk hunts occurring in the 1960's, controversy of drilling for oil and natural gas in the 1970's, and increased use of the forest for recreational opportunities in the last 50 years (MDNR 2007). Hence, the PRC is arguably more popular and promoted due to its historical nature, unique characteristics that have been conserved through guidelines provided by the COM, and provisions for more tourism infrastructure than the ASF. The PRC provides numerous amenities for recreational users with a staffed headquarters that provides information on local plants and wildlife (e.g., brochures, specimens, taxidermy displays); maps for wildlife viewing, recreational trails, and camping; and an award-winning “Discovery Center” which hosts environmental education programs, promotes natural resources stewardship through displays and an interpreter, describes the history of conservation in the PRC, and provides visitors with information for recreational opportunities and regulations (PRCA 2020). We believe the lower observed recreational intensity in the ASF may be due in part to its juxtaposition to the larger, more publicized, and well-developed tourism infrastructure of the PRC.

Although we captured more than twice the number of events in the PRC than the ASF during fewer overall camera hours and documented greater overall RRI, direct comparison between regions were limited due to differing camera placement strategies necessitated by differences in recreational regulations and associated visitor use patterns. Allowance of off-trail activity creates challenges for assessing recreational activities and patterns. For example, equestrian users in the ASF may avoid all forest roads and edges to have a more challenging or primitive riding experience. However, while estimating recreational use in the ASF required additional trail cameras and time to identify recreational user patterns for camera placements, our different sampling strategies allowed us to successfully quantify trail-based recreational intensity, group sizes, and temporal use patterns for both regions. We documented that differences in regulations, trail systems, amenities, proximity to human development, storied history, and marketing of these state forests provide different recreational opportunities that ultimately lead to differences in intensities, group sizes, and primary types of trail-based recreational use.

CHAPTER 3: ELK SPACE-USE AND RESOURCE SELECTION PATTERNS IN RESPONSE TO SUMMER TRAIL-BASED RECREATION

INTRODUCTION

The increased use of public lands for a growing diversification of outdoor recreational activities in the early 21st century has resulted in rising concerns of the effects to wildlife and their habitat (Steven et al. 2011, Cordell 2012, Larson et al. 2016). A growing body of research has examined numerous perceived effects from recreational use on wildlife populations and communities such as changes in behavior (Jayakody et al. 2008, Naylor et al. 2009, Fortin et al. 2016), physiology (Thiel et al. 2011, Harris et al. 2014, Arlettaz et al. 2015), abundance (Mallord et al. 2007, Patthey et al. 2008, Wolf et al. 2013), and community composition (Miller et al. 1998). Although wildlife responses to recreational activity may range from relatively short-term behavioral reactions (e.g., flight responses; Papouchis et al. 2001, Stankowich 2008) to longer term effects (e.g., avoidance of disturbed areas; Neumann et al. 2009, Coppes et al. 2017b), both can have direct negative effects such as increased stress, reduced reproductive success, and decreased foraging (Shively et al. 2005, Arlettaz et al. 2015, Spitz et al. 2019).

Long-term effects of consistent interactions between wildlife and recreational users, such as avoidance of frequently used areas, create challenges for managers attempting to provide wildlife habitat components. Wildlife avoidance of areas used by recreational users can lead to indirect habitat loss and has been observed in large herbivores such as red deer (*Cervus elaphus*), mountain caribou (*Rangifer tarandus caribou*), and elk (*Cervus elaphus nelsoni*) (Sibbald et al. 2011, Lesmerises et al. 2018, Wisdom et al. 2018). Additionally, wildlife responses to recreational activity may lead to numerous indirect effects appearing as human-wildlife conflicts such as vehicle collisions and agricultural crop depredation (Coppes et al. 2017a). Wildlife professionals attempting to manage wildlife population sizes and their spatial distributions should consider the potential direct and indirect effects of encounters with recreational users occurring within or near wildlife habitats (Neumann et al. 2011, Coppes et al. 2018, Heinemeyer et al. 2019). Furthermore, it is vital to understand the differences in the effects caused by different types of recreational use occurring at varying intensities and temporal periods (Boyle and Samson 1985, Larson et al. 2016).

In Michigan, there has been an increase in trail-based recreation (e.g., equestrian use, mountain biking, ORV use) on public lands within the elk range during the last 50 years (MDNR 2007, MDNR 2012). Increased reports of elk causing agricultural depredation outside of their core range has raised concerns among natural resource managers over the potential impacts of recreational activities on elk movements and behaviors (B. Mastenbrook, MDNR, personal communications). Consequently, natural resources managers have hypothesized elk may be selecting areas with less recreational activity. The Michigan elk population has remained relatively stable since approximately 2006 (i.e., mean=1,065, 95% CI = 931–1,200; S. Adams, MDNR, personal communication). Hence, elk occurrences outside of the current range may not be due to population growth. Research examining elk habitat suitability and potential on public and private lands within the range indicates an abundance of cover types supporting elk habitat requirements, suggesting elk may not be selecting sites outside of their range for habitat components (Williamson et al. 2021). Notably, 30% of the public land within the elk range was composed of high-quality food sources for elk (e.g., 16% northern hardwoods/maple, 11% openings, 3% regenerating aspen). While elk habitat is managed relatively consistently across public lands within the Michigan Department of Natural Resources (MDNR) defined elk range, recreational guidelines differ between the Pigeon River Country (PRC) State Forest and Atlanta

State Forest (ASF) Management Units. The PRC's recreational guidelines were established in its Concept of Management (COM), which are specific to the PRC due to its designation as a Special Management Unit (MDNR 2007). These guidelines led to regulations limiting equestrian use and mountain biking to designated trails, while prohibiting ORV use (MDNR 2016).

Our objectives were to: 1) evaluate and compare space-use patterns and resource selection for Michigan elk in response to habitat suitability and the intensity of summer trail-based recreation types (i.e., equestrian use, hiking/foot-traffic, mountain biking, ORV use) at different temporal periods (i.e., year, month, day, hour) for the PRC and ASF; and 2) provide recommendations to natural resource managers challenged with balancing objectives for managing elk, their habitat, and diverse recreational opportunities on state forests. Based on previous findings of elk avoiding frequently used areas by recreational users (Rogala et al. 2011, Wisdom et al. 2018), we predicted that during peak periods of summer trail-based recreational intensity (i.e., May, September, weekends, mid-day; Williamson et al. in review) elk would: 1) have greater monthly home-range sizes and daily movement distances; 2) exhibit increased activity during typical periods of inactivity (e.g., mid-day); 3) use areas of relatively lower habitat suitability; and 4) use areas farther from roads and recreational trails. Finally, based on previous findings of ORV use having greater effects on elk than other types of recreation (e.g., equestrian use, hiking, mountain biking; Naylor et al. 2009, Wisdom et al. 2018), we predicted that the above-mentioned predictions would be more pronounced in the ASF since ORV use is prohibited in the PRC.

METHODS

Elk Capture

Personnel from Wildlife Helicopter Services (Austin, TX, USA), MDNR, and Michigan State University (MSU) captured elk in the PRC and ASF regions of the elk range using net-gunning techniques during February 2016 (Schemnitz 1996, Walsh 2007). Our goal was to capture an equal sex ratio and spatial distribution of elk between and within each region. Captured elk were ear tagged and fitted with a collar (Vectronic Aerospace GmbH, Berlin, Germany; VERTEX Plus Iridium) that included a Global Positioning System (GPS) receiver and a very high frequency (VHF) beacon transmitter. Collars deployed on bull elk included polyurethane foam inserts to accommodate neck swelling during rutting periods. To redeploy collars collected after mortality events in 2016, personnel from the MDNR immobilized an elk by administering 2 ml of butorphanol-azaperone-medetomidine via a 2-ml Pneu-Dart Type 'P' RDD (Pneu-Dart, Williamsport, PA, USA) dart and a Pneu-Dart X-caliber dart gun and used 0.5 ml of Naltrexone and 4 ml of Atipamezole via syringe for reversal. To redeploy refurbished and additional new collars following 2017 mortality events and collar failures, we used the same personnel and methods described for our 2016 capture during winter 2018. All capture and handling procedures were developed and reviewed by the MDNR's wildlife veterinarian and approved by the MDNR.

Elk Locations

Collars calculated locations every 30 minutes during 1–May to 30–September (i.e., peak summer trail-based recreation period), 2016–2018. Collars were programmed to drop-off on 15–January, 2019. Locations were stored on-board and on a server maintained by Vectronic Aerospace that was accessible using a password login. Collar locations were retained if at least 4 satellites were used and the dilution of precision (DOP) was <10.0 (i.e., estimated error is ≤15 m for approximately 99.6% of locations; C. Kochanny, Vectronic Aerospace, personal communication). We estimated collar accuracy by placing collars in open and medium–heavy forest canopy cover areas and recorded GPS locations using a handheld GPS receiver (GPSMAP 64s, Garmin International, Olathe, KS, USA).

Elk Movement and Behavior

We investigated elk movement and behavioral responses during peak periods (i.e., May, September, weekends, mid-day) of summer trail-based recreational intensity in the PRC and ASF (Williamson et al. in review). To evaluate cow and bull elk movement and behavior patterns at multiple spatial and temporal scales, we quantified elk summer (i.e., 1–May to 30–September) home ranges, monthly (i.e., May–September) home ranges, daily movement distances, and hourly patterns of circadian movement behavior. We used a dynamic Brownian bridge movement model (dBBMM; Kranstauber et al. 2012) to estimate summer and monthly home range sizes (i.e., 50% and 95% utilization distributions [UD]) for each sex in each region. The dBBMM is an extension of the standard Brownian bridge movement model (BBMM; Horne et al. 2007) that allows for changes in movement patterns across temporal periods. Specifically, the dBBMM uses a sliding window, maximum likelihood estimation, and the Bayesian information criterion to determine Brownian motion variance (σ_m^2) at different time steps, and subsequently applies the traditional BBMM using separate estimates of σ_m^2 (Kranstauber et al. 2012; Horne et al. 2007). We used a location error of 15 m, a moving window size of 13, and a margin of 3 in the dBBMM computation (Byrne et al. 2014).

We calculated daily linear movement distances for elk using the sum of consecutive 30-minute increment GPS locations within a 24-hour period as an estimate of the total distance moved each day for individual elk (Devore et al. 2016). Days with missing locations (i.e., < 48) were not included in our analysis. Median daily linear movement distances for each elk and each day of the week were averaged across months and years and one-way analysis of variances (ANOVA) were used to assess differences between cows and bulls in the ASF and PRC and across the days of the week. We examined the greatest linear daily elk movement distances by extracting outliers to identify patterns between sexes, regions, and among days of the week. Outliers were identified by extracting linear daily elk movement distances > Q3 + 1.5 × interquartile range [IQR].

We evaluated changes in elk circadian movement behavior throughout the day (i.e., 0:00 – 24:00) by estimating σ_m^2 for individual elk at 1-hour intervals for each day of the week averaged across months and years. Median σ_m^2 was calculated for each hour interval for each day and Kruskal–Wallis tests were used to assess for differences among sexes, regions, and days of the week during each interval. An alpha level of 0.05 was used for all tests for significance. The move package in R was used to calculate dBBMMs (Kranstauber et al. 2020).

Elk Resource Use

To investigate the effects of recreational intensity on elk resource use, we examined resource selection of cows and bulls at different spatial and temporal scales. The primary goal of our landscape–scale analyses was to determine which cover types had the greatest probability of use by cows and bulls in the ASF and PRC during May–September, 2016–2018. The goal of our home range–scale analyses was to determine if use of cover types within cow and bull home ranges varied during peak periods of recreational intensity (i.e., May, September, weekends, mid-day).

Landscape-scale resource use

We performed multiple resource selection analyses (Nielson and Sawyer 2013) to evaluate use of cover types by cows and bulls within the ASF and PRC. Michigan DNR forest inventory data was used in ArcGIS version 10.6.1 (Environmental Systems Research Institute, Redlands, CA, USA) to delineate polygon layers for 7 cover type categories (i.e., openings, aspen, northern hardwoods/maple, oak, other hardwoods, upland conifers, lowland conifers) for all public lands within each region. To account for declines in browse use as age of aspen increases (Campa 1989, Campa et al. 1993, Raymer 2000), we divided our aspen cover type polygon layer into 2 sublayers based on age (i.e., regenerating aspen [<7 years of age], aspen [≥7 years of age) (Williamson et al. 2021). We accounted for changes in the spatial distribution and structure of cover types due to ongoing forest management practices (e.g., clearcutting) by evaluating MDNR forest inventory data each year for 2016–2018. The mean size of openings and regenerating aspen stands in the ASF and PRC were calculated to evaluate for differences between the regions due to different management guidelines in the COM (e.g., restrictions for even-aged forest management treatments [i.e., clearcuts] to be no greater than approximately 16 ha in the PRC; MDNR 2007).

We overlaid cover type polygon layers onto a 30 x 30 m grid (Williamson et al. 2021) and determined the number of elk locations occurring within each 30 x 30 m grid cell for each temporal period (i.e., year, month, day of week, hour of day). To model the probability of elk use for each cover type during each year, generalized linear mixed models (GLMM) were used with a negative binomial distribution to account for overdispersion in the data that resulted from a large number of pixels that did not contain elk locations (Breslow and Clayton, 1993). Models were fitted separately for cows and bulls in each region (Ruhl 1984, Beyer 1987, Walsh 2007).

Our response variable was the number of times an individual elk was detected in a 30 x 30 m grid cell. We included a random effect of individual elk in each model to account for non-independence between locations from the same elk (Devore et al. 2016). Cover types were included as indicator variable fixed effects in each GLMM, taking value 1 if that 30 x 30 m pixel was of the specific cover type and value 0 if the pixel was a different cover type. The natural log of the total number of elk GPS locations was included as an offset term in each GLMM to interpret model coefficients for the probability of elk use rather than for the number of elk locations (Nielson and Sawyer 2013, Devore et al. 2016).

Home range-scale resource use

The patterns of cover type selection within elk home ranges were quantified using the 50% and 95% UDs calculated in our dBBMMs. We considered cover types within the 95% UDs as available and 50% UDs as selected to evaluate changes in cover type selection patterns during different time periods (i.e., month, day, hour) (Byrne et al. 2014, Silva et al. 2018). Proportions of cover types occurring in elk 95% UDs were averaged across years (i.e., May–September, 2016–2018) for individuals (i.e., to avoid pseudoreplication) and then averaged across individuals for each sex in each region. To compare elk selection patterns to proportions of available cover types occurring in 95% UDs, we calculated the proportions of elk locations occurring in each cover type within 50% UDs for each individual elk during each time period. We averaged the proportions of elk locations for individual elk across time periods (e.g., year, month, day of week) during each respective temporal category, and calculated the mean proportional 50% UD cover type use for cows and bulls in the ASF and PRC. Analyses were conducted in R (R Core Team 2018).

Influence of Habitat Suitability and Recreational use of Roads and Trails

Elk use of suitable areas

To further investigate how elk resource use may be affected by recreational intensity, we sought to determine if elk used areas of greater habitat suitability within their range and if suitability of elk locations varied during peak periods of recreational intensity (i.e., May, September, weekends, mid-day). We used a Michigan elk habitat suitability model for spring food created by Williamson et al. (2021) to identify suitability values of each 30 x 30 m grid cell on public lands across the elk range and for each elk location. Although our spring food model was designed to evaluate habitat requirements for elk occurring in spring (i.e., March–May), elk feeding behavior in Michigan is similar throughout the summer and fall months (i.e., June–November) and suitability ratings are assumed to relate directly to quality of habitat from spring to fall (Beyer 1987, Williamson et al. 2021). Suitability values were estimated based on each grid cell's value to provide spring food based on its cover types, stand-level attributes (e.g., age, canopy closure, size, shape), and spatial juxtaposition to other cover types (Williamson et al. 2021). To determine whether elk selected areas with greater habitat suitability within the elk range, we compared mean habitat suitability of all grid cells found within bull and cow elk home ranges to all grid cells within the PRC and ASF. To determine whether elk selected for portions of their home ranges with greater habitat suitability, we compared the mean habitat suitability of all grid cells within 95% (i.e., available) and 50% (i.e., used) UDs for bulls and cows in each region. To determine whether habitat suitability of elk locations changed during peak periods of trail-based recreation (i.e., May, September, weekends, mid-day; Williamson et al. in review), we used ANOVAs to assess for differences in mean habitat suitability among temporal periods (i.e., month, day, hour) for cows and bulls in each region.

Elk use of areas near roads and trails

To further investigate how use of cover types may be affected by recreational intensity, we examined the spatial relationships between elk locations and recreational trails and roads on public lands during peak periods of recreational intensity (May, September, weekends, mid-day). We examined distances to roads and trails at landscape– and home range–scales to determine if elk were disproportionately using locations farther from roads and trails and if distances differed during peak periods of recreational intensity. Thus, we quantified distances to roads and trails within the elk range (i.e., landscape–scale) and within elk 95% UDs (i.e., home range–scale). Previous research documented responses of wildlife to human recreation may vary depending on cover type (van der Zande et al. 1984, Thiel et al. 2007, Coppes et al. 2018). Additionally, cover types were not evenly distributed across the elk range and provide different habitat components for elk (e.g., food, hiding cover, thermal cover). Thus, we performed separate analyses for regenerating aspen, openings, and northern hardwoods/maple based on their greater observed use within our resource selection analyses and their potential to provide greater habitat suitability than other cover types (Williamson et al. 2021). Although each cover type provides highly suitable food sources for elk, openings provide no cover, regenerating aspen stands provide horizontal (i.e., hiding) cover, and northern hardwood/maple stands provide horizontal and vertical (i.e., thermal) cover (Beyer, 1987, Williamson et al. 2021). For analyses in the ASF, we combined roads and trails since there was only 1 primary multi-use trail in the region (Figure 3.1). Roads and trails (i.e., multi-use, biking, equestrian) were evaluated separately in the PRC.

For our landscape–scale analyses, Mann-Whitney *U* tests were used to compare the average median distance of cow and bull locations to the median distance of all possible locations (i.e., each 30 x 30 m grid cell) to roads and trails within each cover type (i.e., regenerating aspen, openings, northern hardwoods/maple) in each region. For our home range–scale analyses, we used Mann-Whitney *U* tests to compare the average median distance of cow and bull locations (i.e., averaged across individuals) within 50% UDs to the median distance of all possible locations (i.e., each 30 x 30 m grid cell) to roads and trails for each cover type within 95% UDs. To further evaluate for differences in elk median distances to roads and trails within home ranges during peak summer trail-based recreational periods (i.e., September, weekends), Kruskal-Wallis tests were used to evaluate for differences among months (i.e., May–September) and days of the week. We did not evaluate for differences among hours since elk use of cover types varied with time of day resulting in insufficient data for comparisons. For example, in openings in the ASF we recorded >1000 cow locations each hour from 3:00–8:00, while recording <100 locations each hour from 15:00–20:00. An alpha level of 0.05 was used for all tests for significance. All statistical analyses were performed in R statistical software (R Core Team 2018) using the pgirmess (Giraudoux 2018) package and visualized using the ggplot2 (Wickham 2016) package.

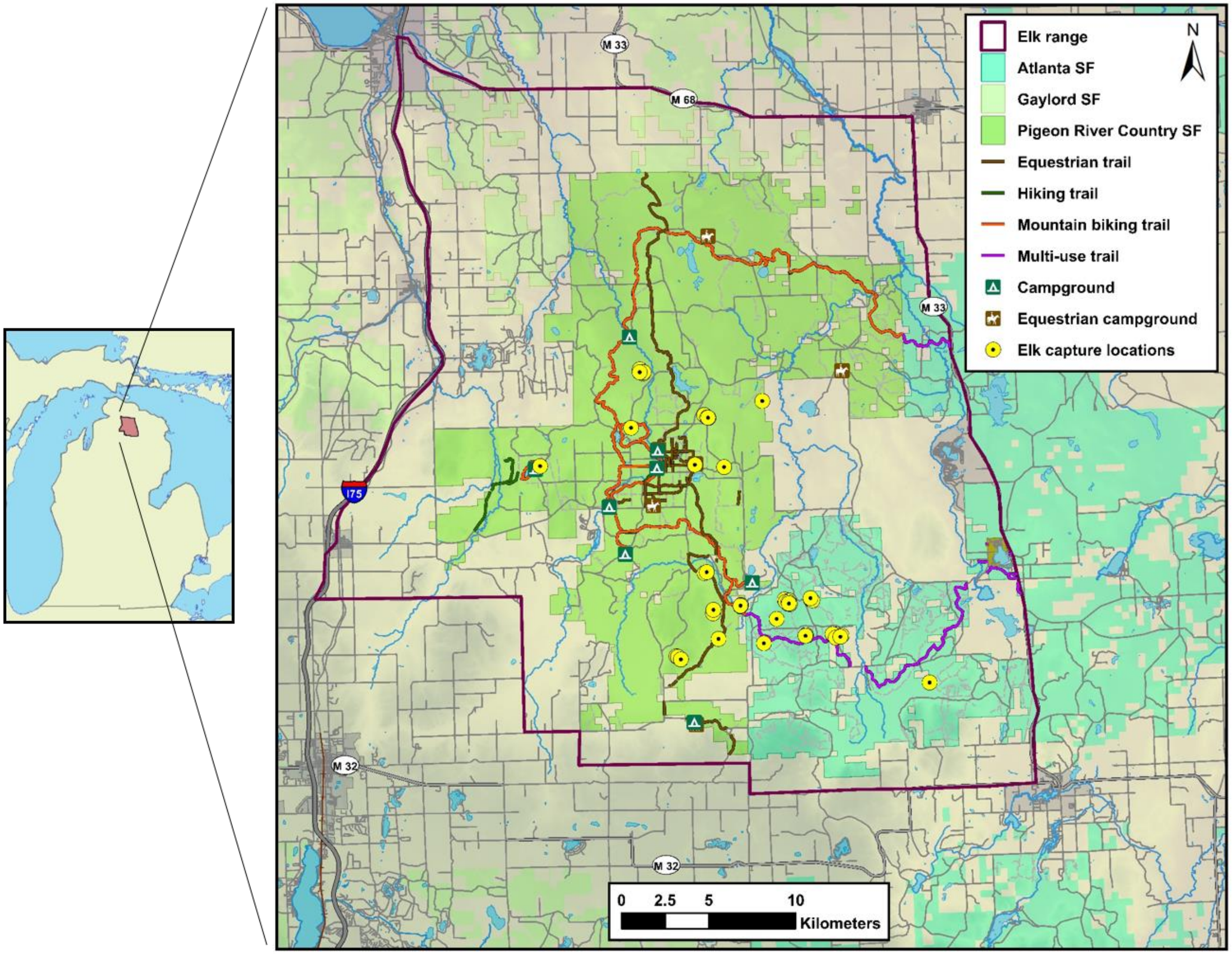


Figure 3.1. Elk capture and GPS-collaring locations and recreational trails and campgrounds within the Michigan Department of Natural Resources designated elk range in the northern lower peninsula of Michigan. Elk capture and collaring was during 15–16 February, 2016 (n=40, 18 PRC, 22 ASF), 9 April, 2017 (n=1, ASF), and 22 February, 2018 (n=12, 7 PRC, 5 ASF).

RESULTS

Elk Capture

During 15–16 February, 2016, 40 adult elk (20 m, 20 f) were captured in the PRC (7 M, 11 F) and ASF (13 M, 9 F) (Figure 3.1, APPENDIX A). On 9 April, 2017, MDNR personnel immobilized and collared an additional bull elk in the ASF. On 22 February, 2018, 8 refurbished and 4 new collars were deployed on 7 adult elk in the PRC (5 M, 2 F) and 5 cow elk in the ASF.

Elk Locations

We recorded 764,758 elk locations during 1–May to 30–September, 2016–2018. We removed 467 locations that had DOPs ≥10.0 or <4 satellites were used, and retained 764,291 locations of which 98.6% (753,961) were within the elk range (i.e., 48.9% = PRC, 33.9% = ASF, 17.2% = private land; Table 3.1). In 2016, 2017, and 2018, we recorded 277,913 (PRC = 46.5%, ASF = 36.4%, private = 17.1%), 217,162 (PRC = 46.1%, ASF = 35.9%, private = 18%), and 258,886 (PRC = 53.7%, ASF = 29.7%, private = 16.6%) locations within the elk range, respectively.

Two collar failures (i.e., stopped providing GPS fixes, intermittent) occurred in 2016, 7 in 2017, and 16 in 2018 (APPENDIX B). The mean fix success rate for collars that did not fail (n = 28) was 99.5% (SD = 0.007, range = 95.7–99.8%). We recorded 108 locations to evaluate precision and accuracy of GPS collars in open and full forest canopy cover testing sites. Mean linear error was 3.61 m (SD = 1.94, range = 0.18–9.13) in open areas (n = 59) and 7.48 m (SD = 5.92, range = 0.93–27.28) in full canopy cover areas (n = 49). Fourteen collars were collected from 2016–2020 following mortality events primarily through hunter harvests (APPENDIX B).

Elk Movement and Behavior

Mean summer elk home range estimates (dBBMM 95% UD) averaged across 2016–2018 were larger ($P < 0.01$) in ASF than in PRC and were larger ($P < 0.01$) for bulls in both regions (Table 3.2). Mean summer core area estimates (dBBMM 50% UD) averaged across years were similar between cows and bulls while being larger ($P < 0.01$) in ASF than PRC (Table 3.2). No significant differences ($P < 0.05$) in mean home range or core area sizes were detected among years for either sex or region. Mean monthly (i.e., May–September) home range sizes were larger ($P < 0.05$) in May than June–September for cows in both regions and bulls in the ASF (Table 3.3). Mean monthly home range size for bulls in the PRC was largest in May, but we found no significant differences ($P < 0.05$) among months (Table 3.3). Mean monthly core area sizes were: 1) larger ($P = 0.03$) in May than September for cows in the ASF; 2) larger ($P < 0.01$) in May than June–September for bulls in the ASF and cows in the PRC; and 3) larger ($P < 0.01$) in May than July–September for bulls in the PRC (Table 3.3).

Average median daily linear movement distances were larger in the ASF than the PRC for cows (+211 m) and bulls (+86 m), but differences between regions were not significant ($\alpha = 0.05$). We found no significant differences among days of the week for cow or bull elk mean daily linear movement distances in the ASF or PRC averaged across all time periods (i.e., May–September, 2016–2018) and during each month averaged across years. However, average median daily linear movement distance was greatest on Friday and Saturday for cows in ASF and Saturday and Sunday for bulls in ASF and cows and bulls in PRC (Table 3.4). We extracted 347 outliers representing the longest daily linear distances traveled by elk (i.e., >7.5 km [> Q3 + 1.5 × IQR]), of which: 1) 63% were from bulls; 2) 55% were in ASF; 3) 42% were in May, 23% in June, 18% in September, 13% in July, and 4% in August; and 4) 70 occurred on Saturday, 54 on

Sunday, 49 on Friday, 46 on Monday, 45 on Thursday, and 42 on Tuesday, and 41 on Wednesday.

Average median hourly elk Brownian motion variance (σ_m^2) was greatest between 6:00–8:00 and 19:00–21:00 for bulls and cows in the ASF and PRC (Figure 3.2). Notably, σ_m^2 typically increased between 3:00–6:00 and 16:00–20:00 and decreased between 8:00–11:00 and 21:00–1:00. No differences were detected in hourly σ_m^2 between bulls and cows or between regions. Few differences ($P < 0.05$) were detected in hourly σ_m^2 among days of the week and time of day for either sex in either region, of which none occurred during peak periods (i.e., weekends, mid-day) of recreational intensity or were ecologically relevant.

Table 3.1. Locations of GPS-collared elk on public (i.e., Atlanta State Forest [ASF], Pigeon River Country State Forest [PRC]) and private lands inside and outside of the Michigan Department of Natural Resources designated elk range in northern lower Michigan from 1–May to 30–September, 2016–2018.

	Inside of elk range			Outside of elk range	
Year	ASF	PRC	private	public	private
2016	101,097	129,367	47,449	0	1,345
2017	77,927	100,165	39,070	2,431	668
2018	76,841	139,054	42,991	2,145	3,741
Total	255,865	368,586	129,510	4,576	5,754

Table 3.2. Mean summer (i.e., 1–May to 30–September) elk home ranges (i.e., 95% utilization distribution [UD]) and core areas (i.e., 50% UD) as estimated by dynamic Brownian bridge movement models in Atlanta State Forest (ASF) and Pigeon River Country (PRC) State Forest in the northern lower peninsula of Michigan, 2016–2018.

		95% UD size (ha)			50% UD size (ha)		
Region/sex	N	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range
ASF							
Cows	12	936	215	478–1,248	115	31	70–183
Bulls	14	1,160	187	726–1,723	120	23	67–179
PRC							
Cows	13	676	160	363–1,057	93	14	63–124
Bulls	10	886	209	452–1,770	96	13	54–127

Table 3.3. Mean monthly elk home ranges (i.e., 95% utilization distribution [UD]) and core areas (i.e., 50% UD) as estimated by dynamic Brownian bridge movement models in Atlanta State Forest (ASF) and Pigeon River Country (PRC) State Forest in the northern lower peninsula of Michigan during summer 2016–2018.

	Cows					Bulls				
		95% UD size (ha)		50% UD size (ha)			95% UD size (ha)		50% UD size (ha)	
Region/month	N	$\bar{x}$	SD	$\bar{x}$	SD	N	$\bar{x}$	SD	$\bar{x}$	SD
ASF										
May	13	602	221	46	12	14	799	214	65	14
June	12	355	115	35	8	14	484	131	44	9
July	12	395	136	40	8	14	504	137	40	9
August	12	384	92	40	11	14	395	82	36	6
September	12	366	110	34	10	14	460	176	36	9
PRC										
May	13	452	161	53	10	10	489	192	53	15
June	13	246	79	31	7	10	442	219	41	15
July	13	308	69	33	5	10	354	92	33	9
August	12	286	81	33	7	11	299	60	30	6
September	12	340	139	34	7	10	449	235	35	11

Table 3.4. Average median elk daily linear movement distances (km) in Atlanta State Forest (ASF) and Pigeon River Country (PRC) State Forest in the northern lower peninsula of Michigan, 2016–2018.

	ASF				PRC			
	Cows (n = 13)		Bulls (n = 14)		Cows (n = 13)		Bulls (n = 11)	
Day	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Monday	4.08	1.34	4.20	1.53	3.96	1.38	4.00	1.54
Tuesday	4.14	1.43	4.16	1.51	3.94	1.33	4.10	1.83
Wednesday	4.04	1.37	4.02	1.40	3.95	1.27	4.12	1.66
Thursday	4.09	1.41	4.19	1.47	3.85	1.14	4.12	1.68
Friday	4.22	1.49	4.26	1.44	4.01	1.33	4.06	1.59
Saturday	4.15	1.50	4.38	1.66	4.17	1.45	4.40	1.85
Sunday	4.13	1.50	4.39	1.51	4.04	1.38	4.22	1.79

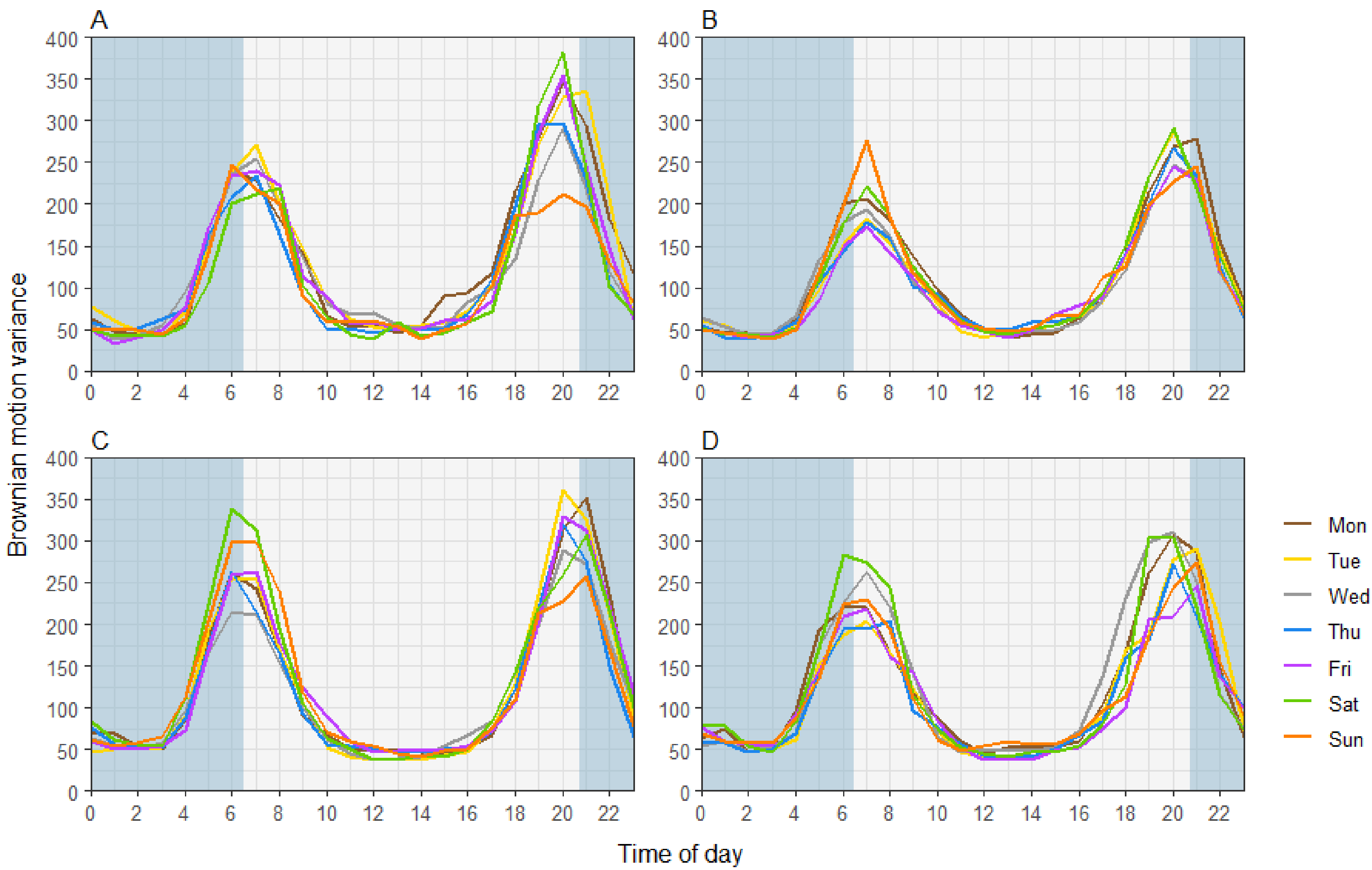


Figure 3.2. Average median hourly Brownian motion variance (σ_m^2) for GPS-collared elk in the Atlanta State Forest (A = cows [n = 13], B = bulls [n = 14]) and Pigeon River Country (C = cows [n = 13], D = bulls [n = 11]) State Forest in the northern lower peninsula of Michigan from May–September, 2016–2018. Gray-filled areas represent mean times of day between sunset and sunrise during our monitoring periods.

Elk Resource Use

Landscape-scale resource use

Delineations of cover types for the PRC (45,840 ha) and portions of the ASF (16,800 ha) within the elk range revealed minor changes in proportions (i.e., 0.1–0.6%) of cover types among years in the PRC and ASF. For example, area of regenerating aspen (<7 years of age) increased in the PRC from 2016 (880 ha) to 2017 (990 ha) and 2018 (1,100 ha) due to clearcutting mature aspen stands. Similar proportions (i.e., within <3%) of openings, regenerating aspen, northern hardwoods, oak, and lowland conifers occurred between the PRC and ASF. The PRC had proportionally more (7.9–8.4%) aspen (≥7 years of age), while the ASF had proportionally more other hardwoods (i.e., 3.2–3.3%) and upland conifers (i.e., 4.8%). In the PRC, the proportional distribution of cover types was 22.4% (SD = 0.24%) aspen (≥7 years of age), 21% (SD = 0.06%) upland conifers, 17.3% lowland conifers, 15.9% northern hardwoods/maple, 10.7% (SD = 0.05%) openings, 5.6% other hardwoods, 2.4% oak, and 2.3% (SD = 0.25%) regenerating aspen. In the ASF, the proportional distribution of cover types was 25.8% (SD = 0.06%) upland conifers, 16.9% lowland conifers, 14.2% aspen (≥7 years of age), 13.4% (SD = 0.11%) northern hardwoods/maple, 12.2% (SD = 0.06%) openings, 8.9% (SD = 0.05%) other hardwoods, 4.9% oak, and 1.5% regenerating aspen. The mean size of openings was 3 ha (n=667, min=0.004 ha, max=57 ha, median=1 ha) in the ASF and 3 ha (n=1,204, min=0.059 ha, max=130 ha, median=1 ha) in the PRC. The mean size of regenerating aspen stands was 7 ha (n=36, min=1.4 ha, max=52 ha, median=4 ha) in the ASF and 8 ha (n=120, min=0.3 ha, max=33 ha, median=7 ha) in the PRC.

The greatest relative probability of cow and bull elk use was in either openings or regenerating aspen each year (i.e., May–September) in each region (Figure 3.3). In the ASF, openings had the greatest relative probability of use in 2016 (0.269) and 2017 (0.547) for cows and in 2016 (0.299) and 2018 (0.233) for bulls (Figure 3.3). Regenerating aspen had the greatest probability of use in 2017 (0.258) for bulls and 2018 (0.306) for cows in the ASF. The only cover type with greater probability of use than regenerating aspen was upland conifers used by cows in 2016 (0.192) and 2017 (0.263) and other hardwoods used by bulls in 2016 (0.171) in the ASF. We found no use of regenerating aspen (< 7 years old) by cow elk in the ASF in 2017 (Figure 3.3). However, probability of cows in the ASF using openings and upland conifers increased from 2016 to 2017 by 103% and 37%, respectively. Conversely, probability of cows in the ASF using openings and upland conifers decreased from 2017 to 2018 by 53% and 81%, respectively, while probability of using regenerating aspen (0.306) increased to a greater probability of use than openings (0.259) (Figure 3.3). For bulls in the ASF, probability of use was relatively consistent among years for all cover types except for regenerating aspen which increased 95% from 2016 to 2017. In the PRC, regenerating aspen had the greatest relative probability of use for cows and bulls each year, followed by openings and northern hardwoods/maple, respectively (Figure 3.3). Probability of using regenerating aspen increased for bulls in the PRC by 17% from 2016 to 2017 and 16% from 2017 to 2018. Lowland conifers had the lowest probability of use each year in each region, except for regenerating aspen by cows in the ASF in 2017.

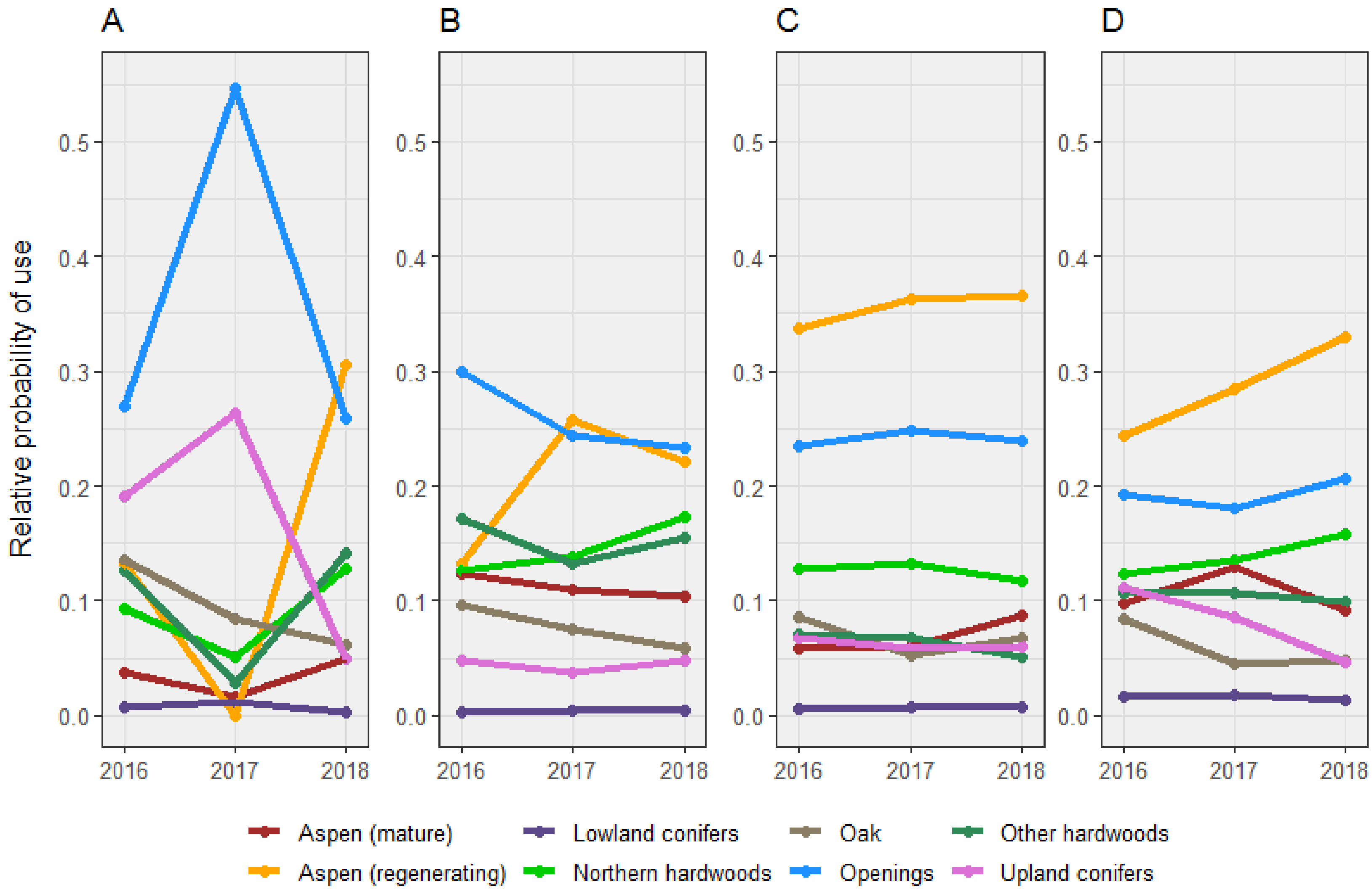


Figure 3.3. Relative probability of use of cover types by GPS-collared elk in the Atlanta State Forest (A = cows [n = 13], B = bulls [n = 14]) and Pigeon River Country (C = cows [n = 13], D = bulls [n = 11]) State Forest in the northern lower peninsula of Michigan from May–September, 2016–2018.

Home range-scale resource use

We found differences between cow and bull cover type proportions, and which cover types composed the majority of 95% UDs in the ASF (Table 3.5). Cow elk 95% UDs in the ASF were primarily composed of upland conifers (28.7%), openings (16.8%), and northern hardwoods/maple (15.7%). Bull 95% UDs in the ASF were primarily composed of mature aspen (20.7%), northern hardwoods/maple (20.6%), and openings (16.4%). In the ASF, cow 95% UDs had proportionally more upland conifers (13.4%), whereas bull 95% UDs had proportionally more mature aspen (9.2%), northern hardwoods/maple (4.9%), and other hardwoods (2.8%). In the PRC, cow and bull mean cover type proportions within 95% UDs were similar with only mature aspen (i.e., 5.9% greater for bulls) and openings (i.e., 5.5% greater for cows) having proportional differences >2% (Table 3.5). Northern hardwoods/maple (cows = 32.2%, bulls = 33.0%), mature aspen (cows = 20.2%, bulls = 26.1%), and openings (cows = 19.9%, bulls = 14.4%) were the most prominent cover types found within cow and bull 95% UDs in the PRC, respectively.

From May–September cow and bull use (i.e., proportion of locations within 50% UDs) of openings and regenerating aspen was greater than availability (i.e., proportion of area within 95% UDs) in both regions during 2016–2018 (Table 3.5). Bulls used mature aspen greater than their availability in both regions from 2016–2018. In the PRC, cows and bulls used other hardwoods greater than their availability from 2016–2018. Openings was the only cover type used greater than their availability during all months (i.e., May–September) by cows and bulls in both regions (Figure 3.4). Cow and bull use of openings was greatest during August in both regions. Elk use of regenerating aspen was greater than availability during all months except for cows in the ASF during August and bulls in the PRC during May, although use was within 1% of availability during both months (Figure 3.4). Cow use of mature and regenerating aspen was greatest in September in both regions. No notable differences were found in use versus availability of cover types by elk among days of the week (Figure 3.5).

Cows and bulls in both regions tended to use regenerating aspen and openings greater than their availability during crepuscular and nocturnal periods (e.g., 18:00–8:00) and less than their availability during daytime hours (e.g., 8:00–18:00) (Figure 3.6). Conversely, elk in both regions tended to use mature aspen, northern hardwoods/maple, and upland conifers greater than their availability during daytime hours and less than their availability during crepuscular and nocturnal hours (Figure 3.6). In the PRC, elk use of other hardwoods was greater than availability during all times of day for bulls and most times of day for cows (Figure 3.6).

Table 3.5. Mean proportions of cover types and elk locations found within GPS-collared elk home ranges (i.e., 95% utilization distribution [UD]) and core areas (i.e., 50% UD) in the Atlanta State Forest (ASF) and Pigeon River Country (PRC) State Forest in the northern lower peninsula of Michigan from May–September, 2016–2018.

	ASF						PRC					
	Female			Male			Female			Male		
Cover type	N	Prop.95[a]	Loc.50[b]	N	Prop.95[a]	Loc.50[b]	N	Prop.95[a]	Loc.50[b]	N	Prop.95[a]	Loc.50[b]
Aspen (mature)	12	0.115	0.088	14	0.207	0.221	13	0.202	0.150	10	0.261	0.275
Aspen (regenerating)	11	0.042	0.055	11	0.028	0.054	13	0.055	0.148	10	0.047	0.113
Lowland conifers	12	0.012	0.008	14	0.015	0.005	12	0.015	0.011	10	0.034	0.019
N. hardwoods/maple	12	0.157	0.107	14	0.206	0.137	13	0.322	0.228	10	0.330	0.230
Oak	12	0.084	0.045	14	0.066	0.038	10	0.021	0.008	8	0.011	0.008
Openings	12	0.168	0.325	14	0.164	0.326	13	0.199	0.318	10	0.144	0.236
Other hardwoods	12	0.126	0.084	14	0.154	0.104	13	0.051	0.052	10	0.047	0.059
Upland conifers	12	0.287	0.285	14	0.154	0.119	12	0.133	0.087	10	0.122	0.060

[a] Proportion of cover types found within elk 95% UDs. Mean proportions of cover types were calculated by averaging individual elk cover type proportions across years before averaging across each group (i.e., females and males in each region).

[b] Proportion of elk locations found within elk 50% UDs. Mean proportions of elk locations were calculated by averaging individual elk location proportions across years before averaging across each group (i.e., females and males in each region).

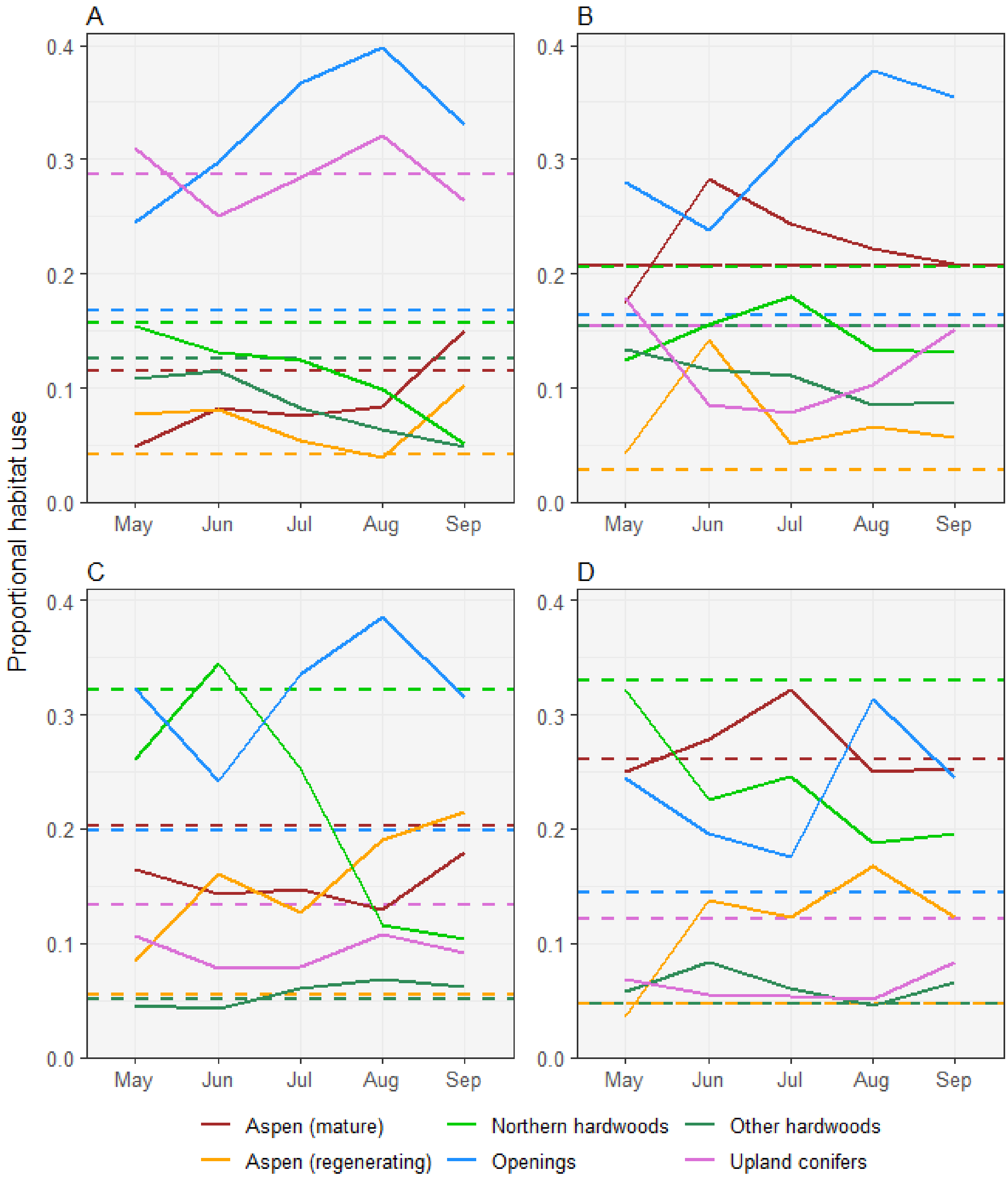


Figure 3.4. Proportional monthly core area (i.e., 50% utilization distribution [UD]) use of cover types within elk home ranges (i.e., 95% UD) in the Atlanta State Forest (A = cows [n = 13], B = bulls [n = 14]) and Pigeon River Country (C = cows [n = 13], D = bulls [n = 11]) State Forest in the northern lower peninsula of Michigan from May–September, 2016–2018. Dashed horizontal lines represent proportional availability of each cover type within elk 95% UDs. Oak and lowland conifer cover types were omitted due to low proportional use during the sampling period.

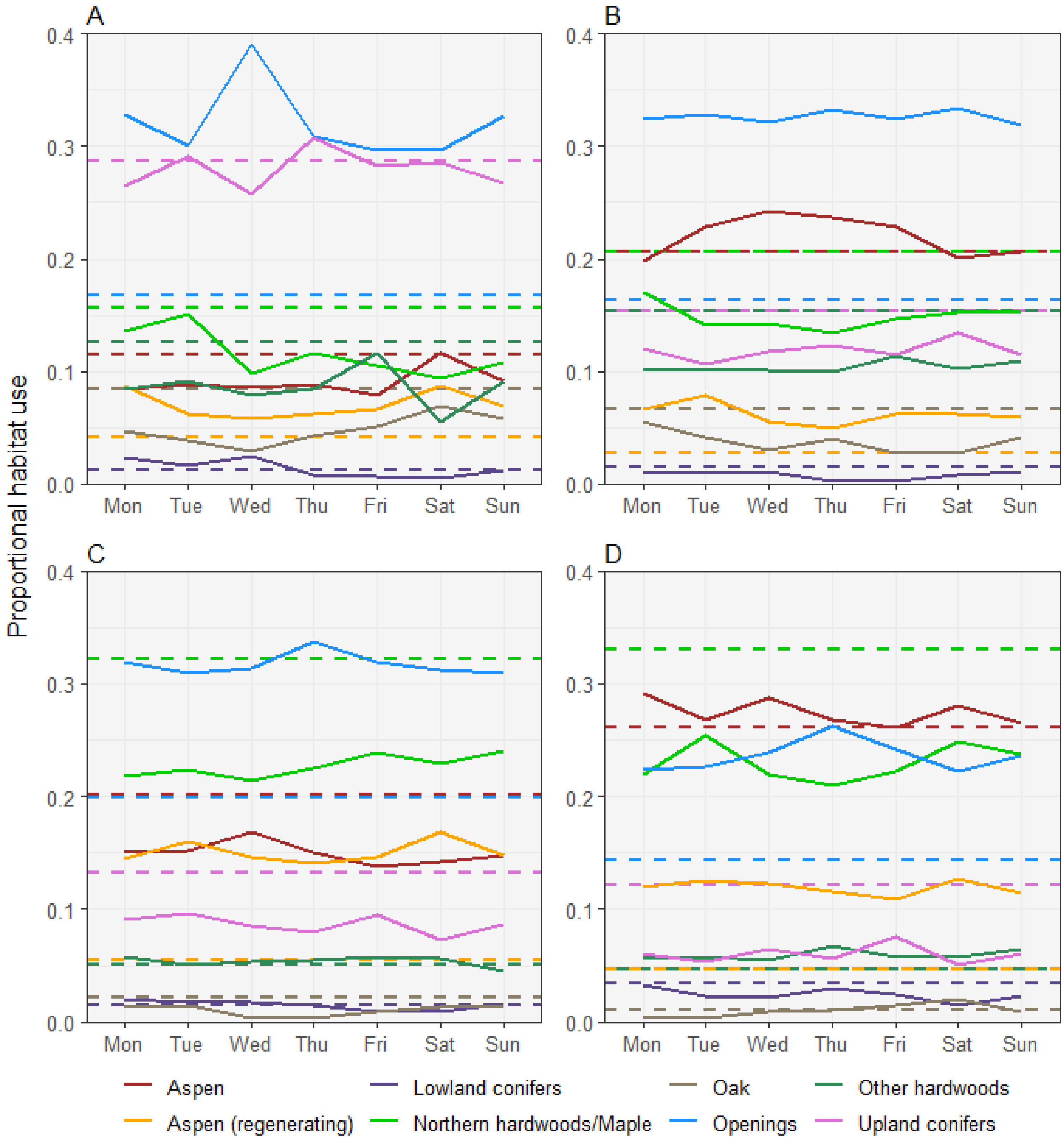


Figure 3.5. Proportional daily core area (i.e., 50% utilization distribution [UD]) use of cover types within elk home ranges (i.e., 95% UD) in the Atlanta State Forest (A = females, B = males) and Pigeon River Country (C = females, D = males) State Forest in the northern lower peninsula of Michigan from May–September, 2016–2018. Dashed horizontal lines represent proportional availability of each cover type within elk 95% UDs.

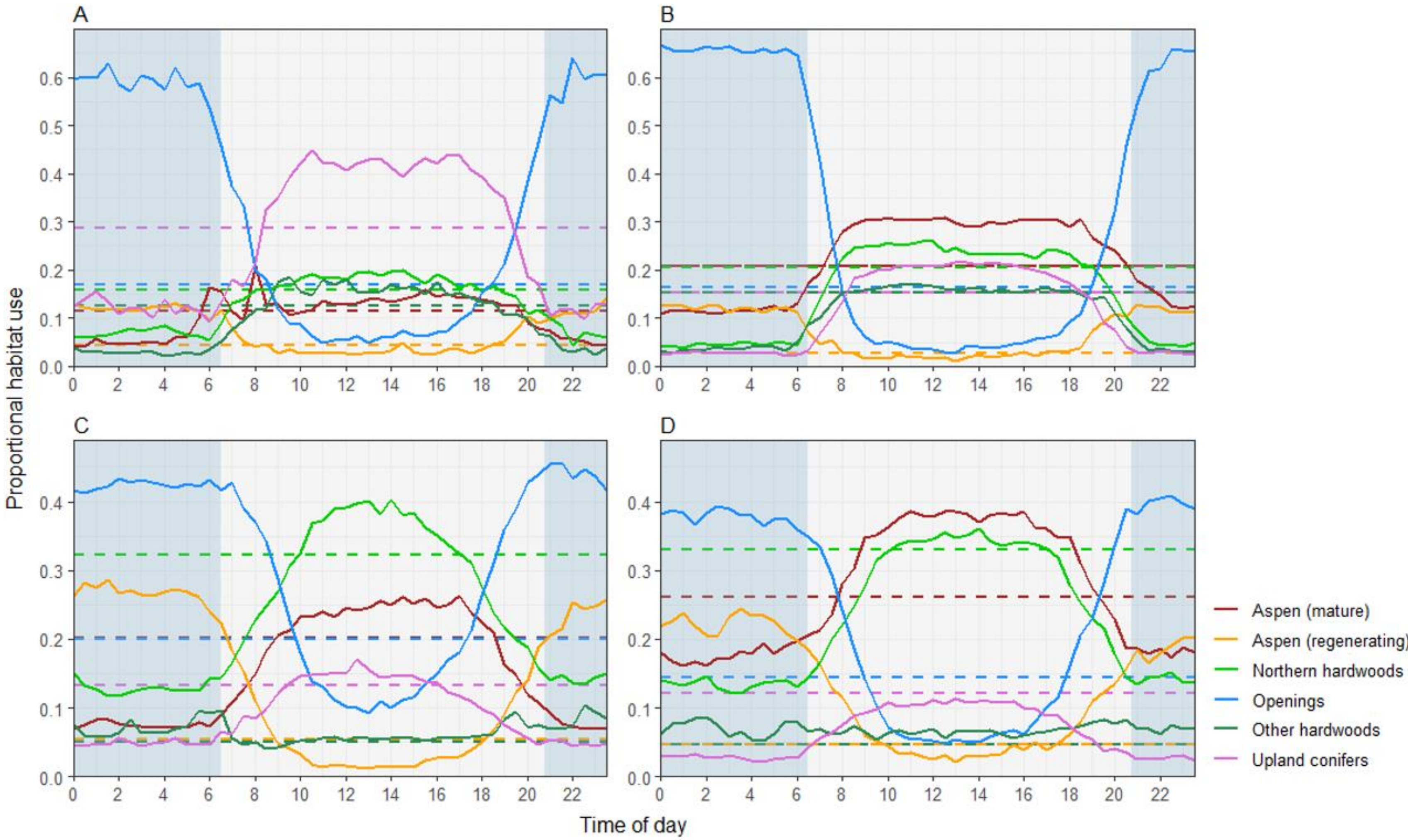


Figure 3.6. Proportional hourly core area (i.e., 50% utilization distribution [UD]) use of cover types within elk home ranges (i.e., 95% UD) in the Atlanta State Forest (A = cows [n = 13], B = bulls [n = 14]) and Pigeon River Country (C = cows [n = 13], D = bulls [n = 11]) State Forest in the northern lower peninsula of Michigan from May–September, 2016–2018. Dashed horizontal lines represent proportional availability of each cover type within elk 95% UDs. Oak and lowland conifer cover types were omitted due to low proportional use during the sampling period. Gray-filled areas represent mean times of day between sunset and sunrise during our monitoring periods.

Influence of Habitat Suitability and Recreational use of Roads and Trails

Elk use of suitable areas

Mean elk habitat suitability for spring food was 0.254 (SD = 0.153) in the PRC and 0.258 (SD = 0.138) in the ASF (Williamson et al. 2021). Elk selected areas of greater habitat suitability for home ranges (i.e., 95% UD) in both regions (ASF = 0.311 ± 0.058, PRC = 0.372 ± 0.086). We found greater ($P < 0.05$) mean habitat suitability within UDs for cows in the PRC (95% = 0.406 ± 0.081, 50% = 0.408 ± 0.091) than for cows in the ASF (95% = 0.280 ± 0.067, 50% = 0.282 ± 0.090), bulls in the ASF (95% = 0.333 ± 0.038, 50% = 0.344 ± 0.052), and bulls in the PRC (95% = 0.323 ± 0.069, 50% = 0.315 ± 0.087). However, no differences ($P < 0.05$) in mean habitat suitability between 95% and 50% UDs were detected for either sex in each region. No differences ($\alpha = 0.05$) in mean habitat suitability within 50% UDs were detected during peak periods of recreational intensity (i.e., May, September, weekends, mid-day) among months, days, and hours for either sex in each region.

Elk use of areas near roads and trails

In the ASF, bull locations in openings had a closer ($P = 0.02$) median distance (61.3 m) to roads or trails than the median distance (108.7 m) of all openings to roads or trails (Table 3.6). In the PRC, cow locations in northern hardwoods/maple had a closer ($P = 0.04$) median distance (459 m) to roads than the median distance (269.2) of all northern hardwoods/maple to roads (Table 3.6). Cow locations in regenerating aspen had a closer ($P < 0.01$) median distance (229.8 m) to trails than the median distance (1.17 km) of all regenerating aspen to trails in the PRC. Cow and bull locations in regenerating aspen, openings, and northern hardwoods/maple had closer ($P < 0.05$) median distances to equestrian trails than the median distances of each cover type to equestrian trails in the PRC (Table 3.6). No differences ($\alpha = 0.05$) were detected between median distances of elk locations to roads and trails in 50% UDs and median distances to roads and trails in elk 95% UDs for cows or bulls in each cover type in each region (Table 3.7). Additionally, we found no differences in median distance to roads and trails during peak periods of recreational intensity (i.e., May, September, weekends, mid-day) among months and days for either sex in each cover type in each region.

Table 3.6. Distances of key cover types (i.e., regenerating aspen, openings, northern hardwoods/maple) and elk locations to the nearest road and trail (i.e., multi-use trail [trail], biking trail [bike], equestrian trail [horse]) in the Atlanta State Forest (ASF) and Pigeon River Country (PRC) State Forest in the northern lower peninsula of Michigan. Elk locations were recorded from GPS-collared elk (n=53, 25 PRC [13 cows, 12 bulls], 28 ASF [14 cows, 14 bulls]) from 1–May to 30–September, 2016–2018.

	ASF		PRC				
		Dist. (road/trail)		Dist. (road)	Dist. (trail)	Dist. (bike)	Dist. (horse)
Cover type/sex	N[1]	median[2]	N[1]	median[2]	median[2]	median[2]	median[2]
Aspen (regenerating)	8,073	84	33,094	170	1,167	2,748	3,915
Cow	3,663	134	20,830	201	230	1,211	711
Bull	7,834	103	10,311	200	789	1,667	1,044
Openings	22,421	109	50,406	373	1,411	2,276	3,073
Cow	18,565	76	63,395	381	1,071	1,906	1,256
Bull	55,647	61	30,551	368	1,053	1,917	1,387
Northern hardwoods	77,009	126	222,733	269	1,159	2,051	2,893
Cow	8,035	185	49,457	459	1,211	2,221	1,447
Bull	30,616	181	34,810	302	966	2,151	1,408

[1] Number of 30 x 30 m grid cells or elk locations within regenerating aspen, openings, or northern hardwoods/maple cover types.

[2] Median distances are the median distance of individual elk median distances (m).

Table 3.7. Distances of primary cover types (i.e., regenerating aspen, openings, northern hardwoods/maple) within elk home ranges (i.e., 95% UD) and elk locations within core areas (i.e., 50% UD) to the nearest road and trail (i.e., multi-use trail [trail], biking trail [bike], equestrian trail [horse]) in the Atlanta State Forest (ASF) and Pigeon River Country (PRC) State Forest in the northern lower peninsula of Michigan. Elk locations were recorded from GPS-collared elk (n=53, 25 PRC [13 F, 12 M], 28 ASF [14 F, 14 M]) from 1–May to 30–September, 2016–2018.

	ASF		PRC				
		Dist. (road/trail)		Dist. (road)	Dist. (trail)	Dist. (bike)	Dist. (horse)
Cover type/sex	N[1]	median[2]	N[1]	median[2]	median[2]	median[2]	median[2]
Openings							
Cow elk 95% UD	14,658	68	42,610	427	922	1,881	1,100
Cow elk 50% UD	12,163	71	38,120	386	985	2,029	1,238
Bull elk 95% UD	37,851	60	23,247	354	941	2,027	1,281
Bull elk 50% UD	34,969	63	16,346	418	1,324	1,860	1,467
Regenerating aspen							
Cow elk 95% UD	3,135	107	11,039	216	257	1,406	874
Cow elk 50% UD	2,520	144	14,629	223	280	1,283	870
Bull elk 95% UD	5,749	93	7,540	193	375	1,153	1,068
Bull elk 50% UD	4,308	78	6,429	207	610	1,940	1,008
Northern Hardwoods							
Cow elk 95% UD	12,621	121	57,593	410	1,005	2,500	1,154
Cow elk 50% UD	3,596	163	23,555	411	1,183	2,034	1,509
Bull elk 95% UD	43,760	159	53,212	282	884	2,085	1,212
Bull elk 50% UD	13,699	173	15,145	299	755	1,893	1,372

[1] Number of 30 x 30 m grid cells or elk locations within regenerating aspen, openings, or northern hardwoods/maple cover types.

[2] Median distances are the median distance of individual elk median distances (m).

DISCUSSION

Our results demonstrated home range-scale changes in elk space-use and resource selection patterns in response to peak periods of summer trail-based recreation in northern lower Michigan. We found no evidence of landscape-level elk avoidance of areas with recreational activity during our study. Our results were similar to those for red deer which found that recreational use strongly affected selection of resources within home ranges but had no effect on selection of home ranges (Coppes et al. 2017a). Our prediction of greater monthly elk home range sizes and daily movement distances during peak periods of recreational intensity (i.e., May, September, weekends) was partially supported by our findings of greater monthly home range sizes in May than June–September and greater daily movement distances during weekends. Williamson et al. (in review) found that recreational intensity of ORV users in the ASF during May was 1.6–2 times greater than June–August, 2016–2018. In the PRC, intensity of equestrian users during May was 3.7–5.9 times greater than June–August (Williamson et al. in review). Notably, 42% of our longest daily linear distances traveled by elk occurred in May. Our observed differences in home range sizes among months were evident in both regions but were most evident in the ASF where cow and bull home ranges were 1.5–1.7 and 1.6–2 times larger in May than June–September, respectively (Table 3.3). Although we did not find greater home range sizes during September (i.e., peak month for summer recreational intensity [Williamson et al. in review]) for either sex or region, elk may have modified movement patterns to use areas with less recreational use during May or habituated to predictable recreational activity throughout the summer months (Lyon and Ward 1982, Thompson and Henderson 1998, Taylor and Knight 2003). Hence, our findings may suggest elk space-use patterns were, in part, affected by the late-spring resurgence of summer trail-based recreational users in the elk range.

Although greater home range sizes and daily movement distances in May could be due to changes in movement and resource selection related to calving and spring green-up (Beyer 1987, Walsh 2007, Lehman et al. 2016), we found no studies that reported greater home range sizes or movement distances by bull elk specifically in May. Notably, Ruhl (1984) reported that cow home ranges in Michigan were larger in spring (2,344 ± 134 ha, n = 2) than summer (1,621 ± 638 ha, n = 6), but bull home ranges were larger in summer (3,717 ± 2,331 ha, n = 3) than spring (3,533 ± 3,754 ha, n = 3). Although bull home ranges were larger in May than June–September in both regions, bull home range sizes in the PRC were only 47 ha larger in May than June while being 315 ha larger in the ASF (Table 3.3). The disparity between regions in observed home range size differences among months may be due to ORV use being prohibited in the PRC. Williamson et al. (in review) found that the intensity of ORV use in the ASF in May ranged from 1.6–5.3 times greater than June from 2016–2018. Thus, our findings of significantly greater ($P < 0.05$) home range sizes for bulls in May than June–August in the ASF may be due to increased recreational intensity of ORV use during May.

Due to the relatively even distribution of openings throughout our study regions, we do not believe larger home range sizes in May were related to bulls expanding ranges to include new food sources provided by openings in late spring. Our findings of bulls in the ASF using proportionally less regenerating aspen and more upland conifers during May and September may suggest that bulls modified their selection of cover types in response to ORV use (Figure 3.4). Notably, May and September were the only months that bulls in the ASF used upland conifers greater than or equal to their availability, respectively. While mature aspen and upland conifer stands provide thermal cover during summer months, upland conifer stands can also provide hiding cover (Beyer 1987). Bulls in the ASF may be expanding home ranges to select areas with hiding cover to limit interactions with ORVs. Similarly, our findings of cows in both regions using proportionally less openings and more regenerating aspen during September may be due to cows using horizontal cover for hiding while feeding. Prior research on elk habitat selection patterns in Michigan documented increased use of openings in September (Ruhl 1984, Moran 1973, Beyer 1987). However, we found a decline in proportional use of openings from August to September for cows and bulls in both regions from 2016–2018 (Figure 3.4). Our observations of cows switching food sources from openings to regenerating aspen during September in both regions may have been attributed to increased trail-based recreational intensity. Previous research has documented increased elk use of hiding cover in response to logging, human disturbances, and recreational use (Edge and Marcum 1985, Buchanan et al. 2014, Wisdom et al. 2018). Williamson et al. (in review) found that overall intensity of summer trail-based recreation (i.e., equestrian use, hiking, mountain biking, ORV use) in the ASF and PRC was greatest in September from 2016–2018. Although other types of recreation (e.g., hunting, wildlife viewing) occur frequently in September, recent research within Michigan's elk range using surveys found that path activities (i.e., hiking, mountain biking, equestrian use) accounted for more visits ($n = 140$) than hunting ($n = 133$) or wildlife viewing ($n = 88$) from June–November, 2018 (Hunt 2019). Changes in cover type selection during September may also be attributed to rutting behavior, however, we found no changes in cover type selection patterns that suggested bulls or cows were selecting cover types to seek or avoid each other during courting.

Although elk home range sizes were not larger during September, greater daily movement distances on weekends from May–September suggests a consistent response to recreational activity despite the changes in intensity of use across months. Although we found no differences ($\alpha = 0.05$) among days of week for elk daily movement distances, distances from Friday–Sunday were greater and accounted for 50% of our longest daily movement distances. Thus, elk may be selecting habitat components within their home ranges that are relatively farther from recreational activities during weekend days than weekdays (i.e., Monday–Thursday).

Although elk exhibited greater daily movement distances during weekends, our findings of no differences in σ_m^2 among days of the week suggest elk travel farther to preferred cover types but do not exhibit irregular behavior during days of greater recreational intensity (i.e., weekends) or at times of the day when elk are typically inactive (i.e., 0:00–4:00, 10:00–16:00). Elk use of preferred cover types for food and cover remained relatively consistent across days of the week, which we attributed to minimal overlap of the crepuscular behavior of elk and typical peak activity periods of trail-based recreation during 2016–2018. Williamson et al. (in review) found that 61% of recreation events occurred between 11:00–17:00 during 2016–2018. Based on our findings of elk σ_m^2 throughout the day, elk exhibited typical crepuscular behavior that resulted in the lowest mid-day periods of inactivity between 10:00–16:00. Thus, human-elk interactions were unlikely during periods of the day when recreational users were most active. These findings may also explain why elk were found at greater distances from roads when in northern hardwoods/maple during mid-day (i.e., 8:00–18:00) bedding periods and at closer distances to trails when in regenerating aspen and openings between evening and early morning hours (i.e., 18:00–8:00).

Our findings for hourly elk resource selection patterns and elk σ_m^2 revealed different patterns of use for preferred food sources during nocturnal and diurnal periods of inactivity. Primary periods of inactivity for cows and bulls in both regions were between 0:00–4:00 and 10:00–16:00. However, elk use of preferred cover types (i.e., openings, regenerating aspen) remained approximately 2–4 times greater than availability between 0:00–4:00 while remaining lower than availability between 10:00–6:00. Thus, elk remained in openings and regenerating aspen during nocturnal periods of inactivity and no recreational activities, but moved to vegetation types providing cover (e.g., upland conifers, northern hardwoods) for diurnal periods of inactivity and increased recreational intensity (Figure 3.6). Our findings were consistent with previous research in Michigan that found similar crepuscular and nocturnal patterns of elk using openings and regenerating aspen (Ruhl 1984). Notably, Beyer and Haufler (1994) found that elk use of openings was 4.5 times greater during nocturnal than diurnal periods. Although our findings may suggest elk are not using preferred food sources due to mid-day periods of increased recreational intensity, previous research documented that forest stands with greater canopy cover reduces direct sunlight thereby providing thermal relief for elk during higher mid-day summer temperatures (Marcum 1975, Skovlin et al. 2002). In Custer State Park in South Dakota (i.e., a region with similar summer temperatures and humidity), elk selected bed sites that favored conditions (i.e., greater canopy cover and lower ambient temperatures) providing thermal cover instead of hiding cover in an area with an extensive network (i.e., 341 km) of roads and trails (Millspaugh et al. 1998). However, Coppes et al. (2017a) found that red deer avoided preferred summer food sources in areas where recreation occurred. Hence, similar to Ruhl (1984), we believe elk may be using mature hardwood and conifer stands between 10:00–6:00 for the combined benefits of thermal and hiding cover that may limit interactions with recreational users.

Our prediction of elk using areas with relatively lower habitat suitability during peak periods of recreational intensity was not supported by our findings. Elk use of areas with greater habitat suitability during peak periods of recreational intensity may be attributed to the abundance of high suitability areas distributed throughout the elk range (Williamson et al. 2021). Coppes et al.

(2018) found that areas of greater habitat suitability reduced the effects of recreational activity to the western capercaillie (*Tetrao urogallus*). Due to the relatively large size and even distribution of cover types providing areas of food and cover for elk in the PRC and ASF, elk likely did not have to travel far (e.g., daily movement distances; Table 3.4) within home ranges to remain in high-suitability areas during intense periods of trail-based recreation. Thus, we attribute the minimized effects of recreational intensity, in part, to an abundance of cover types that provide food (e.g., openings, regenerating aspen) and cover (northern hardwoods/maple, upland conifers) for elk.

Our prediction of elk using areas farther from roads and recreational trails during peak periods of recreational intensity was not supported by our results. While research has demonstrated avoidance of roads and trails by elk during periods of increased human activity (Rowland et al. 2000, McCorquodale 2003, Spitz et al. 2019), others documented elk do not avoid roads with light hunting pressure and may become habituated to consistent use of roads and trails (Millspaugh et al. 1998, Baasch et al. 2010). Roads and trails create edges in forested landscapes which may serve as food sources and travel corridors for elk moving among cover types (Anderson et al. 2005). Although elk selected for openings, regenerating aspen, and northern hardwoods closer to equestrian trails at the landscape–scale, we found no evidence of elk selecting for areas closer to equestrian trails within core areas of their home ranges. Notably, while differences were not significant ($p<0.05$), median distances of elk locations to equestrian trails within openings and northern hardwoods in core areas were greater than median distances within home ranges for cows and bulls. Furthermore, our observed landscape–scale selection of areas closer to equestrian trails was likely not due to elk selecting areas of greater suitability that were coincidentally located near equestrian trails. Mean habitat suitability of areas within 60 m (i.e., mean flight distance for elk in Michigan [Bender et al. 1999]) of an equestrian trail was 0.215, which was lower than the mean habitat suitability within elk home ranges (i.e., cows = 0.406, bulls = 0.323) and for the entire PRC (0.254). Elk selection of home ranges in close proximity to equestrian trails may be related to use of trails as travel corridors during times of the day (i.e., 18:00–8:00) when recreational activity is low. Elk may have also demonstrated a greater tolerance for areas with equestrian use than areas with other types of trail-based recreation. Naylor et al. (2009) found that elk showed some evidence of habituation to equestrian use, but no evidence of habituation to mountain biking, hiking, or ORV (i.e., all-terrain vehicle [ATV]) use. We attribute the selection of home ranges closer to equestrian trails and lack of avoidance of roads, multi-use trails, and mountain biking trails to: 1) a lack of trail-based recreation during typical activity periods for elk (Williamson et al. in review); 2) potentially, a greater tolerance for equestrian use than other types of trail-based recreation (Table 3.6); and 3) the juxtaposition of trails and roads to an abundance of high suitability areas that provided preferred cover types.

Our prediction of more pronounced effects from trail-based recreational intensity in the ASF due to lack of designated trails and ORV use was supported by our results on elk space-use. Cow and bull home range sizes and daily movement distances were greater in the ASF than the PRC. Our findings for elk resource selection patterns did not indicate differences between regions. We believe the lack of differences in elk resource selection between regions provides further support for mitigation of effects due to an abundance of high habitat suitability and differences in recreational regulations between regions. The potential differences in elk responses to the PRC's designation and restriction of recreational activity to trails may partially explain the differences in elk space-use patterns between the regions. Off-road vehicle use is prohibited in the PRC and was the most commonly detected type of recreation during summer months in the ASF (Williamson in review). In Oregon, Priesler et al. (2006) found that elk demonstrated strong patterns of movements to hiding areas during ORV (i.e., ATV) use from mid-April to October, and Wisdom et al. (2018) found that ORV (i.e., ATV) use had a greater effect on elk distances to trails than mountain biking, hiking, and equestrian use, respectively. We attribute greater elk home range sizes and daily movement distances in the ASF to a lack of designated trails and presence of ORVs.

CHAPTER 4: ELK RESPONSES TO EXPERIMENTAL EQUESTRIAN USE AND MOUNTAIN BIKING EVENTS ON PUBLIC LANDS IN MICHIGAN

INTRODUCTION

Human-wildlife interactions have become a focus of wildlife management issues in the early 21st century with human population growth and growing participation in outdoor nature-based recreation (Taylor and Knight 2003, Larson et al. 2016). Although participation in hunting and fishing has declined in recent decades, participation in other types of outdoor recreation (e.g. equestrian use, mountain biking, off-road vehicle [ORV] use, snowmobiling, wildlife viewing) has increased (Cordell 2012). While much research has focused on the negative effects (e.g., changes in habitat use, abundance, physiology) of such recreation types on various taxa, few studies have compared the responses of wildlife to different types of outdoor recreation (Larson et al. 2016).

Recent studies have implemented experimental forms of recreational activity to measure the response and effects of these activities on large mammals such as elk and moose (*Alces alces*) (Naylor et al. 2009, Neumann et al. 2011, Wisdom et al. 2018). In Oregon, Naylor et al. (2009) applied 4 types of recreational activities (all-terrain vehicle use [ATV], mountain biking, hiking, equestrian use) during a 5-day period to 13 GPS radio-collared adult female elk after 14 days of no human activity. Elk activity increased during all 4 recreation types with ATV use causing the most impact, followed by mountain biking, hiking, and horseback riding (Naylor et al. 2009). Similarly, Neumann et al. (2011) exposed 29 adult female moose with GPS radiocollars to off-trail hiking and snowmobiling activity in northern Sweden. Both experimental treatments led to increased moose movements lasting 1-2 hrs and increased movement speed 4-8 times. Energetic costs of moose were estimated to increase by 16% in response to hiking, and by 19% in response to snowmobiling (Neumann et al. 2011). Although both studies demonstrated effects on elk and moose in response to experimental recreation events, replication of studies comparing different types of recreational activity on public lands with different recreational regulations and land use objectives is lacking.

In Michigan, the Pigeon River Country (PRC) State Forest and portions of the Atlanta State Forest (ASF) Management Units are considered the core of elk range and provide numerous outdoor recreational opportunities. In the last 50 years, natural resource managers have observed an increase in trail-based recreation types such as equestrian use and mountain biking (MDNR 2007, MDNR 2012). Mountain biking and equestrian use are among the recreation types that are projected to increase the most per capita in the U.S. in the next 40 years (Cordell 2012). The increase in trail-based recreation in the PRC and ASF has led to concerns over the potential negative effects (e.g., indirect habitat loss, increased human-wildlife conflicts) it may have on the elk population and habitat (B. Mastenbrook, MDNR, personal communications). Although the elk population has remained relatively stable (mean=1,065, 95% CI = 931–1,200; S. Adams, MDNR, personal communication) since 2006, elk occurrences outside of the MDNR's designated range have led wildlife managers to hypothesize that elk may be moving outside of the PRC and ASF in response to periods of increased recreational intensity.

In response to the growing use of public lands in the Michigan elk range by trail-based recreational users, we studied the behavioral responses of elk to equestrian use and mountain biking activity during the peak summer month (September) for trail-based recreational activity (See RESULTS, Chapter 2). Our objectives were to: 1) quantify and compare the behavioral responses of radiocollared elk to experimental equestrian use and mountain biking events in the ASF and PRC; 2) document the typical riding behaviors of equestrian users and mountain bikers within the elk range; and 3) provide recommendations to natural resource managers challenged with balancing objectives for managing elk, their habitat, and trail based recreation on state forests. Based on previous findings of increased elk activity in response to experimental equestrian use and mountain biking events (Naylor et al. 2009, Wisdom et al. 2018), we predicted that: 1) elk would show increased hourly movement behavior in response to interactions with experimental recreation events; 2) recreation events occurring within the mean flight distance for elk in Michigan (i.e., 60 m; Bender et al. 1999) would result in elk movements away from recreation; and 3) movement distance and duration would be greater for mountain biking than equestrian use (Naylor et al. 2009, Wisdom et al. 2018).

METHODS

Experimental Recreation Events

Based on our findings that the greatest recreational intensity of all trail-based recreation in the PRC and ASF occurred in September (See RESULTS, Chapter 2), we planned experimental equestrian use and mountain biking events during September, 2018. We contacted members of the Pigeon River Country Equestrian Committee, Tri-County Horse Association, and Alpena County Horseman's Club in early August, 2018 to recruit riders to participate in the study. We also presented study objectives and methods, distributed informational fliers, and answered questions at a public equestrian users meeting in the PRC equestrian campground on 28–September, 2018 to encourage participation. Mountain biking volunteers were recruited by contacting 7 key individuals that were known to ride in the PRC (S. Whitcomb, MDNR, personal communication) in July–August, 2018. Volunteer equestrian users and mountain bikers were encouraged to exhibit "normal" riding behavior (e.g., ride times, ride areas, ride pace, group size) and were provided with handheld Global Positioning System (GPS; GPSMAP 64s, Garmin International, Olathe, KS, USA) receivers to carry during rides. Handheld GPS units were programmed to record date, time, and locations in 1–minute intervals. Volunteers were asked to record group size and encounters with elk.

Elk Movements and Behavior

We investigated elk activity and movement patterns by monitoring 19 (i.e., PRC = 5 cows, 5 bulls; ASF = 4 cows, 5 bulls) of 34 GPS-collared (Vectronic Aerospace GmbH, Berlin, Germany; VERTEX Plus Iridium) elk (See RESULTS, Chapter 3) during experimental recreation events. Monitored elk were chosen based on proximity to recreational trails (i.e., within the mean maximum daily movement distance [1,690 m; See METHODS, Chapter 1]) during August of 2018. Prior to experimental recreation events, GPS collar programming was modified to record locations in 5-minute intervals to obtain finer resolution elk movements in relation to recreation events than would be available using our standard 30-minute interval programming (See METHODS, Chapter 3). We considered elk encounters with recreational users to be any 5-minute period where elk were within 120 m (i.e., 2 times the average flight distance [60 m] for elk in Michigan [Bender et al. 1999]) of an equestrian user or mountain biker carrying a handheld GPS receiver. To quantify elk movements in response to encounters, we measured the linear movement distance between elk locations at 5-minute intervals from 30 minutes prior to an encounter to 30 minutes after (i.e., 13 5-minute intervals). Linear movement distances for each 5-minute interval were averaged across all elk, and a one-way analysis of variance (ANOVA) was used to assess for differences in mean linear movement distances among 5-minute intervals that occurred before, during, and after elk encounters with recreation events.

To identify changes in hourly elk activity in response to encounters with recreational users, we examined elk Brownian motion variance (σ_m^2) at 1-hour intervals using a dynamic Brownian bridge movement model (dBBMM; See METHODS, Chapter 3). Based on our previous findings of typical elk inactivity during diurnal periods (See Results, Chapter 3), we expected elk σ_m^2 to remain relatively low during typical mid-day riding periods (See Results, Chapter 2) with increases in elk σ_m^2 during hours with encounters with recreational users. One-way analysis of variance (ANOVA) was used to assess for differences in elk σ_m^2 among hours of the day averaged across all elk encounters.

RESULTS

Experimental Recreation Events

We recorded 69 (PRC = 65, ASF = 4) equestrian and 3 mountain biking (PRC = 1, ASF = 2) events from 31–August to 30–September, 2018 (Table C1, APPENDIX C). Mean group sizes were larger in the ASF (equestrian = 6, mountain biking = 3) than in the PRC (equestrian use = 3, mountain biking = 2). The largest group size for equestrian users was 12 in the ASF and 6 in the PRC (Table 4.1). Ride duration, distance, and average speed for equestrian users was similar between the PRC and ASF (Table 4.1). Although the average equestrian use event lasted longer than mountain biking events in both regions, the average speed of mountain bikers was greater than equestrian users (Table 4.1). Start times of equestrian trials ranged from 7:43 to 18:55 (median = 11:48) and end times ranged from 9:14 to 20:07 (median = 14:37). Equestrian groups reported seeing at least one elk during 12 of 65 rides in the PRC and during 3 of 4 rides in the ASF. Mountain biking groups did not report seeing elk in either region during rides.

Elk Movements and Behavior

During 72 experimental equestrian user and mountain biking events, we only recorded 4 encounters (i.e., a GPS-collared elk within 120 m of a recreation event) that occurred between equestrian users and the same cow elk (collar ID = 29868) in the PRC (Table 4.2, Figures 4.2–4.5). Notably, there were only 2 additional equestrian events where riders were within 180 m (i.e., 3 times the average flight distance for elk in Michigan) of a radio-collared elk, and in both cases it was the same cow elk as mentioned above (collar ID = 29868). Although we had GPS-collared elk throughout the PRC, the majority of elk locations were not in close proximity to the core network of recreational trails in the PRC (Figure 4.6). The closest distance of a mountain biking event to a radio-collared elk was 162 m in the ASF. We were unable to calculate the average linear distance between 5-minute intervals between equestrian users and cow elk 29868 due to a delay in the cow's collar receiving the change from 30-minute to 5-minute location programming. However, the collar received the update for 5-minute programming before our final recorded encounter that occurred at 17:40 on 9-27-18 (Figure 4.5). We were not able to perform statistical analyses or examine elk Brownian motion variance (σ_m^2) due to our results being limited to one elk with 4 encounters that occurred during different collar programming schedules (30-minute locations, 5-minute locations). However, the range of linear distances between 30-minute locations occurring from 30 minutes before to 30 minutes after our first 3 encounters was only 1–32 m. The range of linear distances between 5-minute locations from 30 minutes before to 30 minutes after our last encounter was only 8–35 m (Figure 4.2). Thus, we found no evidence of increased movements for cow elk 29868 in response to encounters within 120 m of equestrian users. Furthermore, there was no change in cover type selection of cow elk 29868 during the 30-minute periods following each encounter.

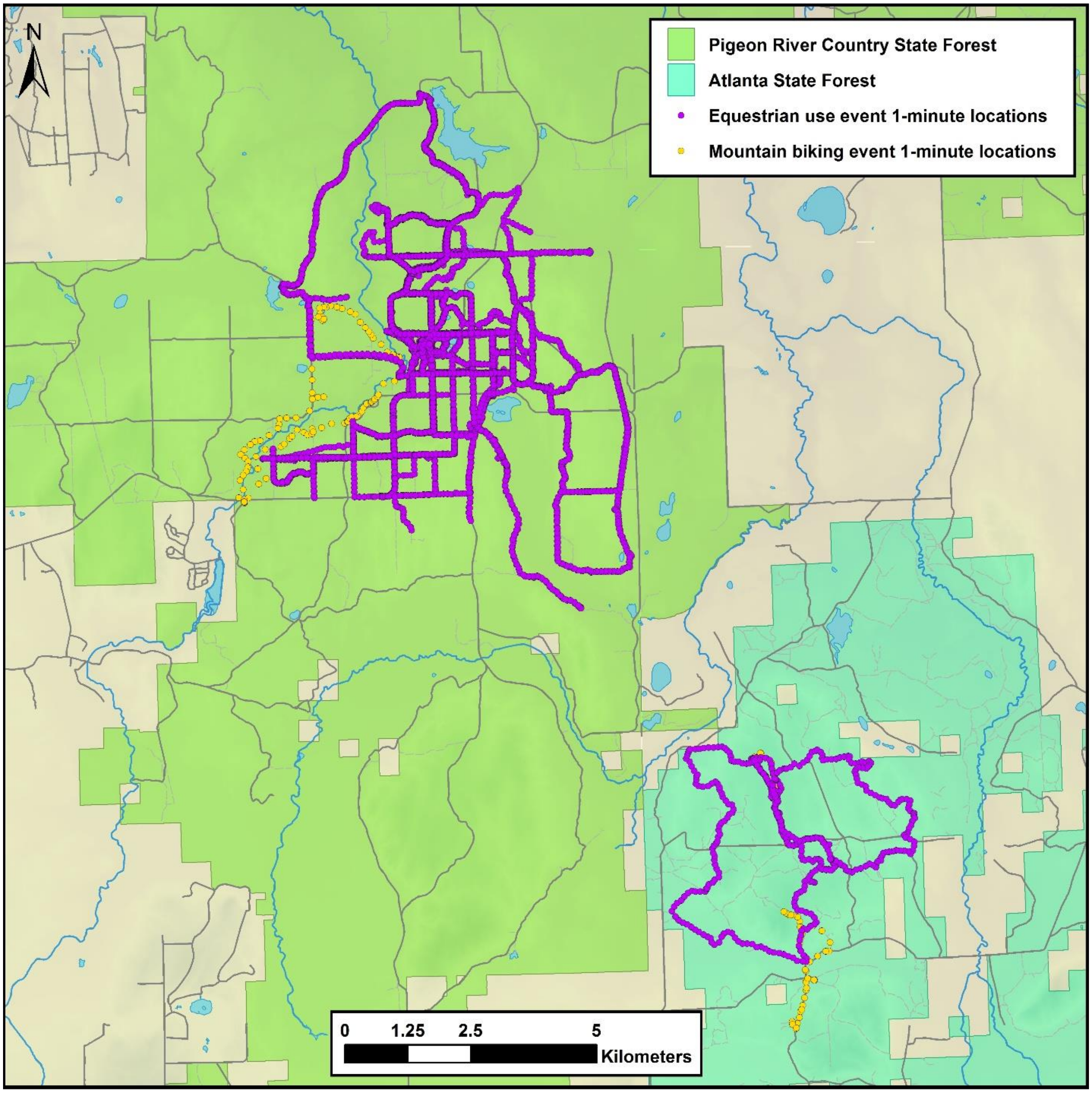


Figure 4.1. Location of experimental equestrian use (n = 69) and mountain biking (n = 3) events within the Pigeon River Country and Atlanta State Forests from 31–August to 30–September, 2018. User locations were recorded in 1-minute intervals using handheld Global Positioning System receivers carried during recreation events.

Table 4.1. Summary of experimental equestrian use and mountain biking events within the Pigeon River Country (PRC) and Atlanta State Forests (ASF) from 31–August to 30–September, 2018.

Recreation type/		Group size		Duration (hr:min)		Distance (km)		Speed (kph)	
region	N	$\bar{x}$	range	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Equestrian use									
ASF	4	6	2–12	2:35	1:10	9.7	4.8	3.8	0.8
PRC	65	3	2–6	2:31	1:13	11.1	5.1	4.5	0.7
Mountain biking									
ASF	2	3	3	0:44	0:14	5.6	1.8	7.6	0.1
PRC	1	2		1:57		13.0		6.7	

Table 4.2. Encounters (i.e., any 5-minute period where elk were within 120 m of an equestrian user or mountain biker carrying a handheld GPS receiver) between equestrian users and elk during experimental recreation events within the Pigeon River Country State Forest from 31–August to 30–September, 2018.

	Group				Elk			
Event type	size	Region	Date	Time	Collar ID	Sex	Distance (m)	Cover type
Equestrian[1]	3	PRC	08-31-2018	11:30	29868	cow	114	opening
Equestrian[2]	2	PRC	09-02-2018	11:30	29868	cow	42	northern hardwoods
Equestrian[3]	2	PRC	09-27-2018	08:30	29868	cow	86	regenerating aspen
Equestrian[4]	2	PRC	09-27-2018	17:40	29868	cow	92	upland conifers

[1] Figure 4.2
[2] Figure 4.3
[3] Figure 4.4
[4] Figure 4.5

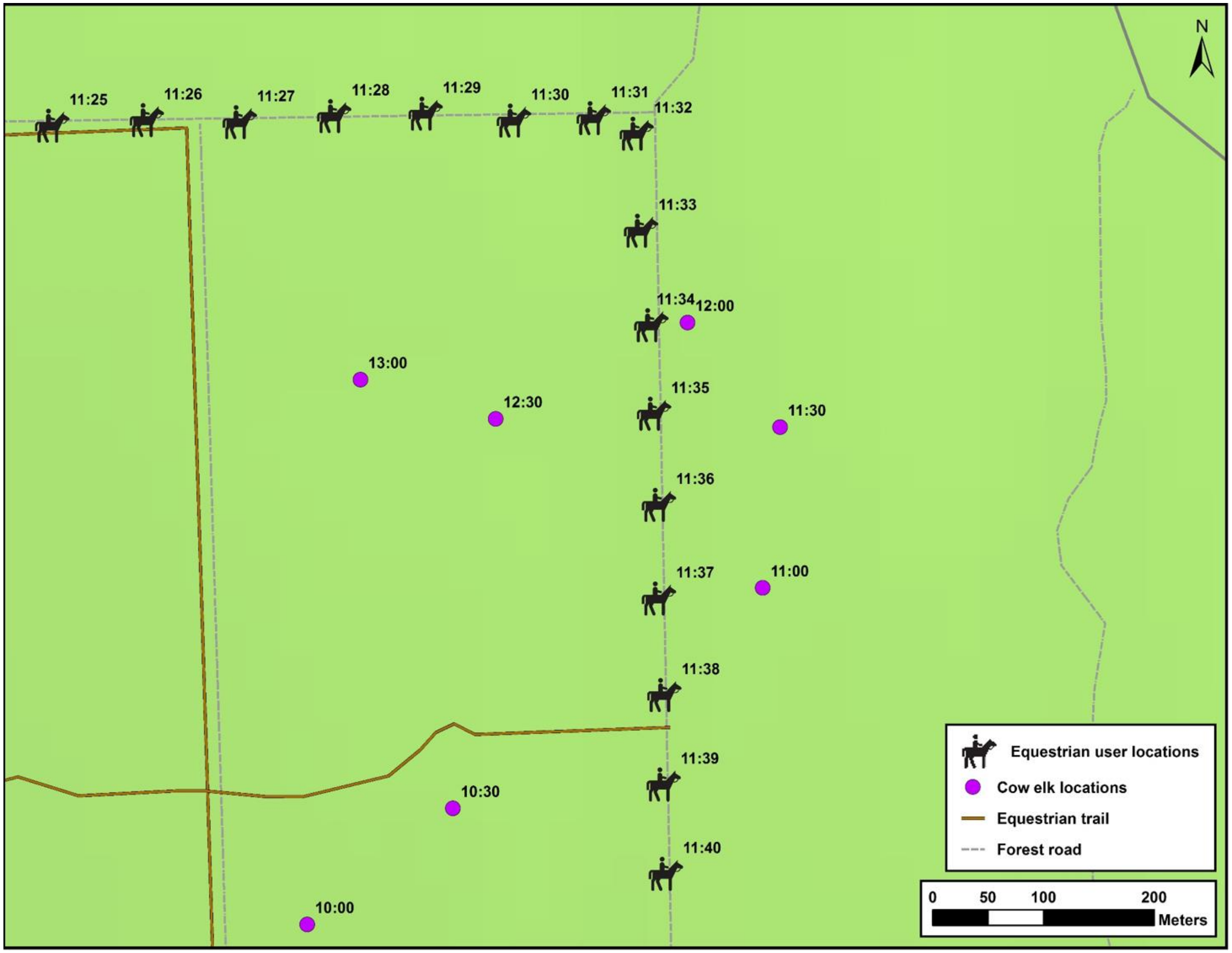


Figure 4.2. Encounter between equestrian users and a cow elk (collar ID = 29868) during an experimental recreation event within the Pigeon River Country State Forest on 31–August, 2018. Cow elk locations shown occurred in 30-minute intervals from 10:00 to 13:00.

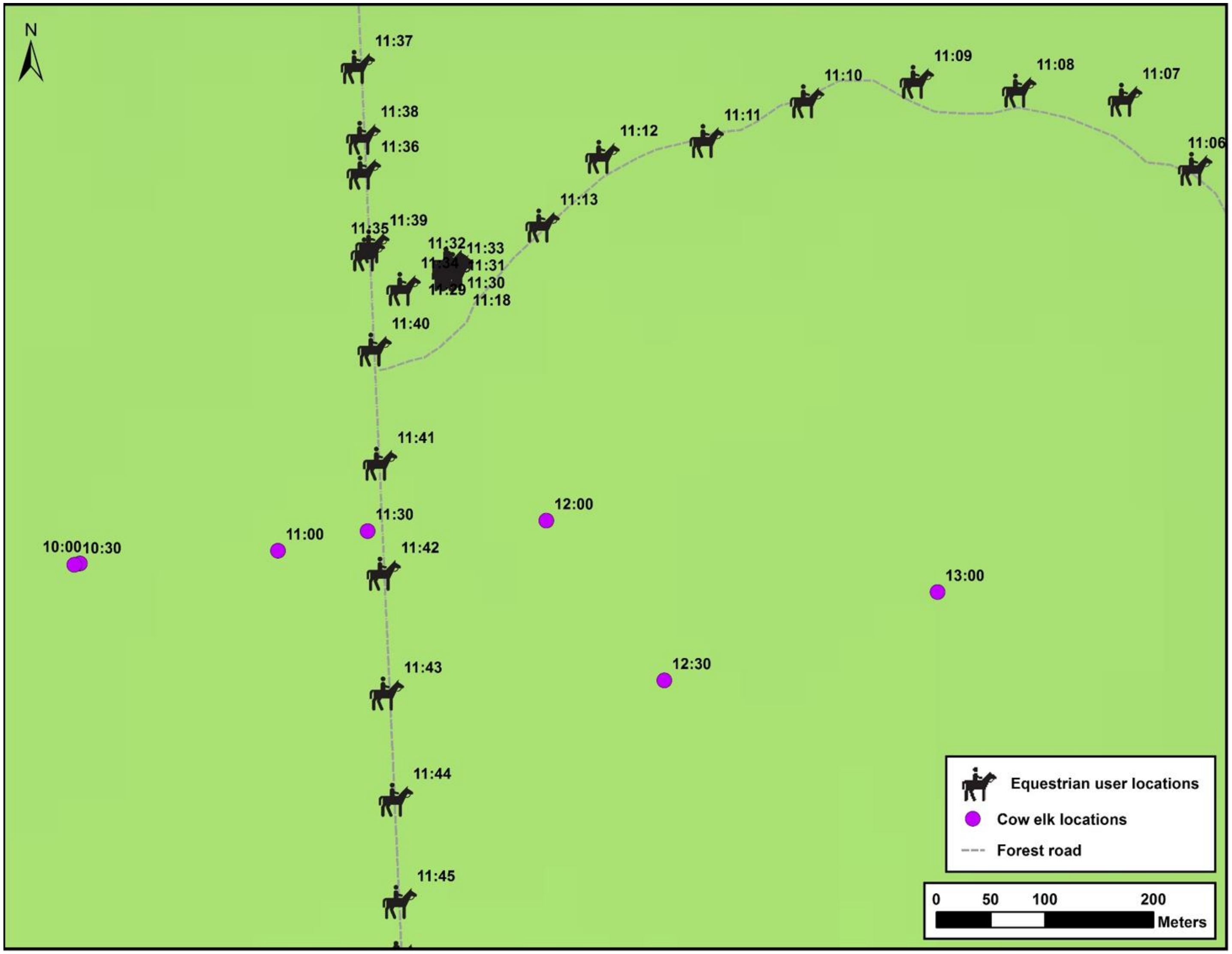


Figure 4.3. Encounter between equestrian users and a cow elk (collar ID = 29868) during an experimental recreation event within the Pigeon River Country State Forest on 2–September, 2018. Cow elk locations shown occurred in 30-minute intervals from 10:00 to 13:00.

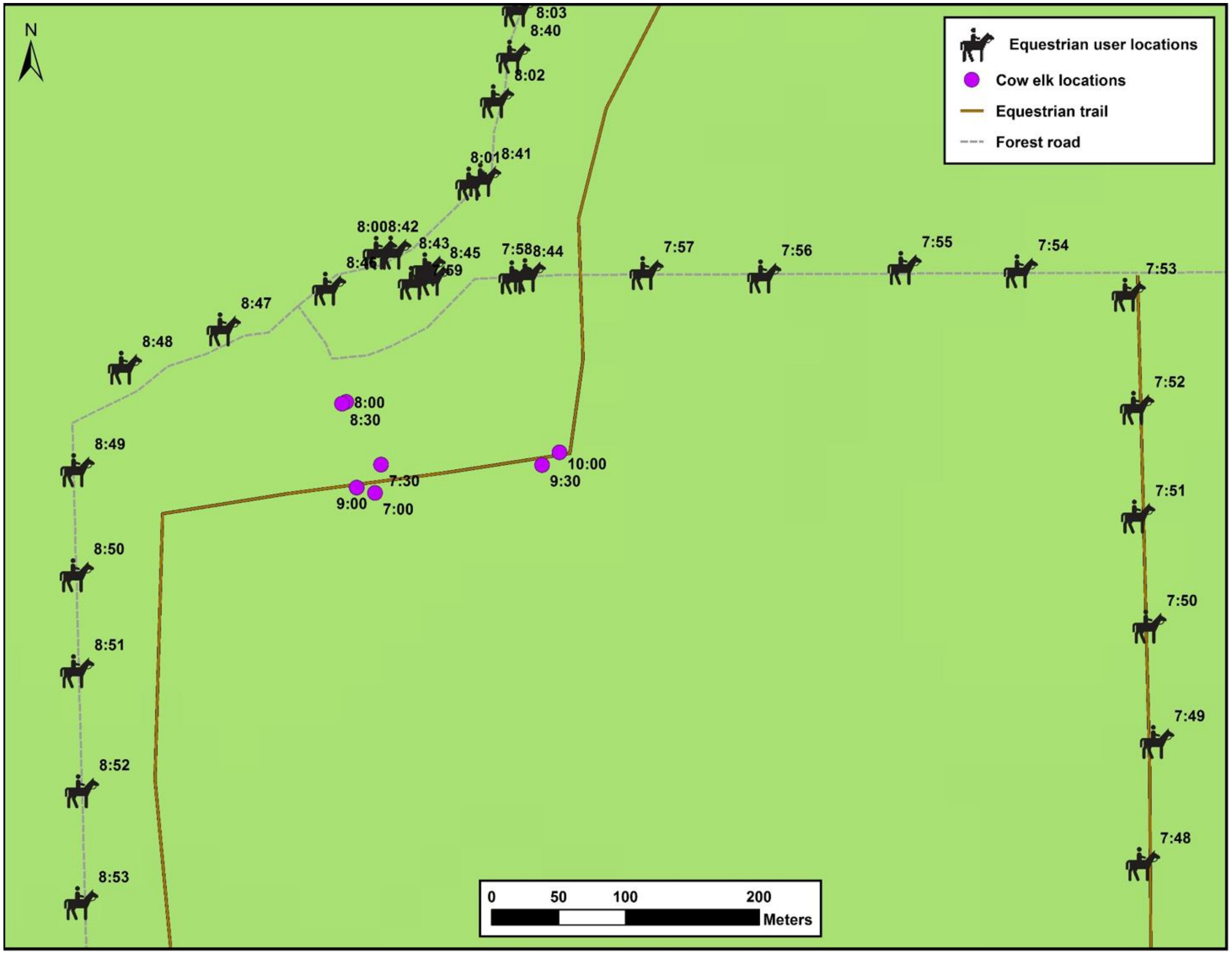


Figure 4.4. Encounter between equestrian users and a cow elk (collar ID = 29868) during an experimental recreation event within the Pigeon River Country State Forest on 27–September, 2018. Cow elk locations shown occurred in 30-minute intervals from 07:00 to 10:00.

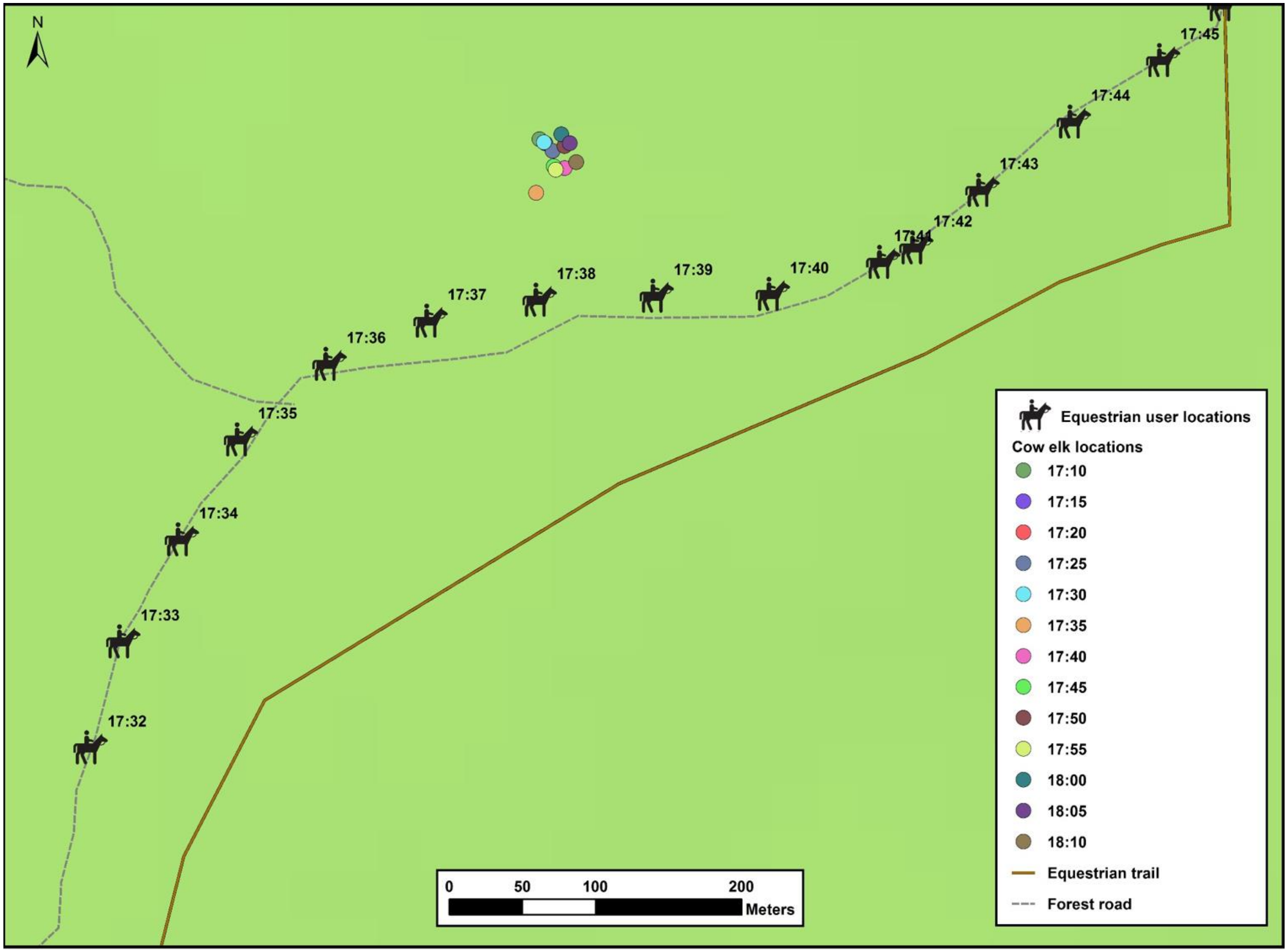


Figure 4.5. Encounter between equestrian users and a cow elk (collar ID = 29868) during an experimental recreation event within the Pigeon River Country State Forest on 27–September, 2018. Cow elk locations shown occurred in 5-minute intervals from 30 minutes before to 30 minutes after the closest linear distance (i.e., 92 m at 17:40) between the equestrian users and the cow.

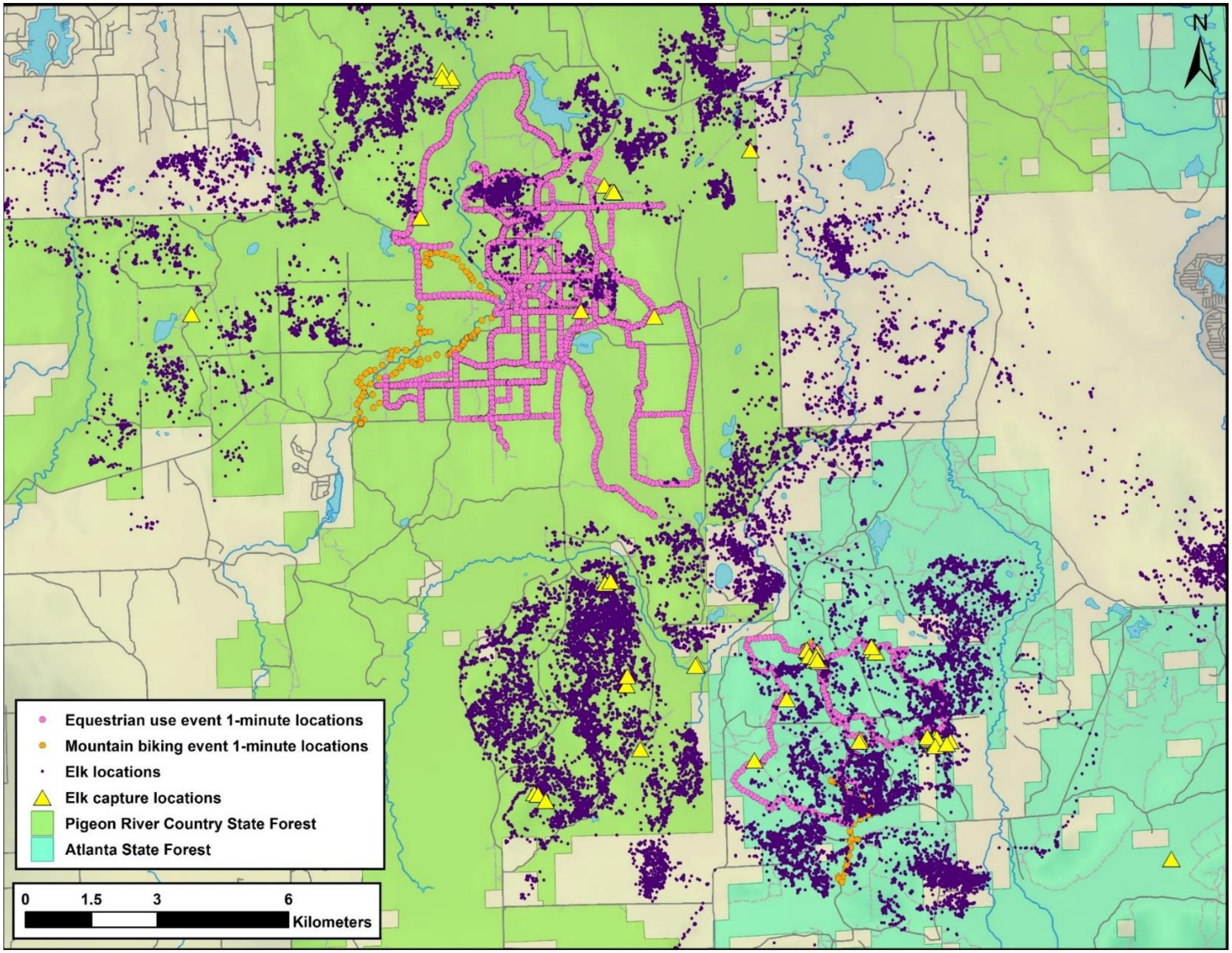


Figure 4.6. Locations of GPS-collared elk and elk capture locations in relation to experimental equestrian use (n = 69) and mountain biking (n = 3) events within the Pigeon River Country and Atlanta State Forests from 31–August to 30–September, 2018.

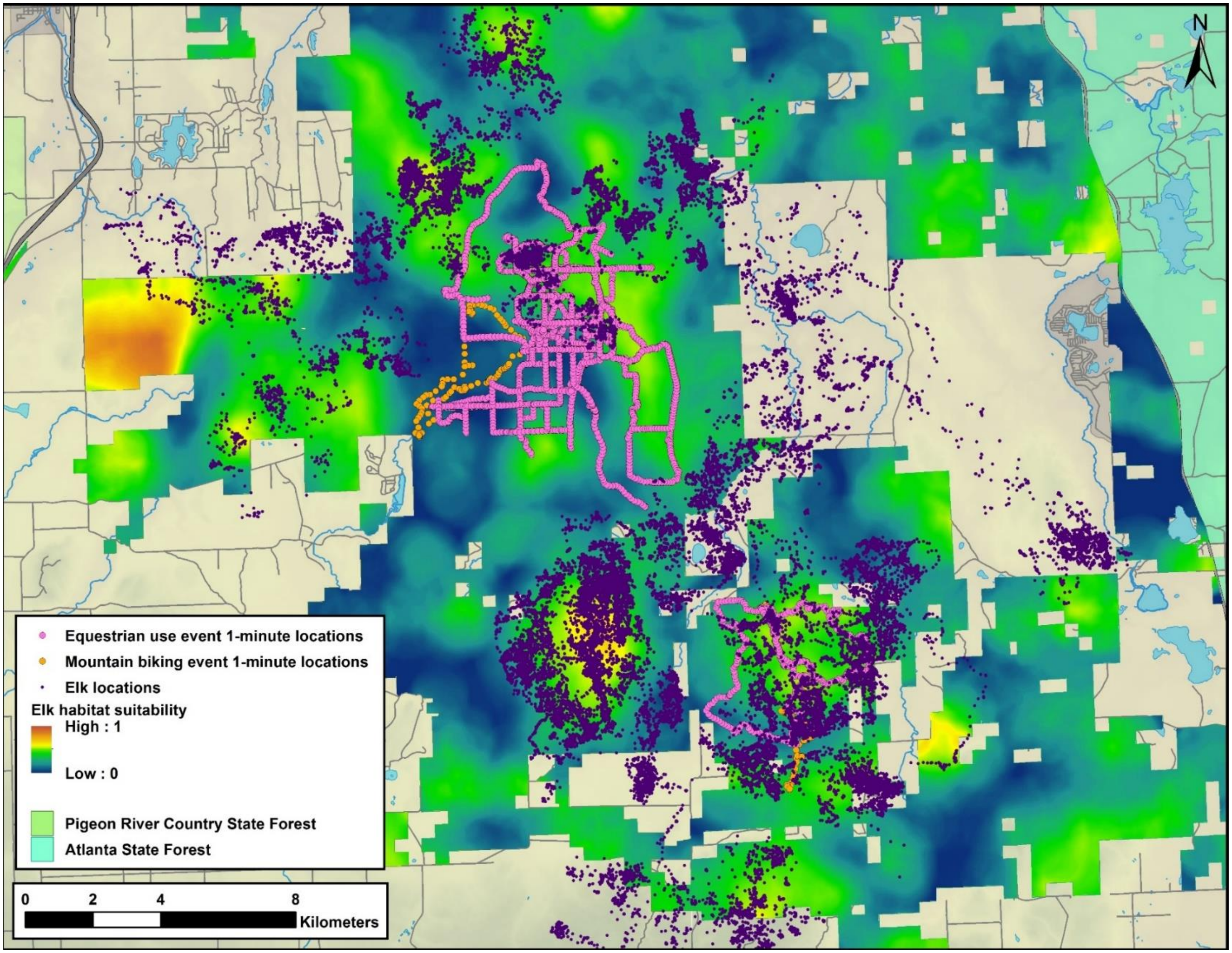


Figure 4.7. Locations of GPS-collared elk in relation to habitat suitability and experimental equestrian use (n = 69) and mountain biking (n = 3) events within the Pigeon River Country and Atlanta State Forests from 31–August to 30–September, 2018.

DISCUSSION

Although we did not find evidence of behavioral responses (i.e., increased movement distances between locations, increased σ_m^2) to experimental recreation events during our study, results were limited to the responses of 1 cow elk to equestrian users in the PRC. We attribute the lack of encounters between GPS-collared elk and experimental recreation events to the absence of GPS-collared elk from the core region of equestrian trails in the PRC where people were riding (Figure 4.6) and limited participation by equestrian users in the ASF and mountain bikers in both regions. During the time of our recreation events (i.e., 31–August to 30–September) we only recorded 1 cow elk (in the PRC) and 1 bull elk (in the ASF) within 3 times the mean flight distance (60 m; Bender et al. 1999) of elk in Michigan to a recreation event. Although we collared a relatively even distribution of elk throughout the study area, 4 of 11 elk that were collared in the PRC within relatively close proximity (< 1 km) to areas where recreation events occurred died (1) or had collar failures (3) before our recreation event period (31–August to 30–September) (Figure 4.6). Thus, the reduced number of collared elk in the core region of the PRC where our riding events were concentrated likely limited the number of encounters between recreational users and elk during our events.

Based on our landscape-level findings of cows and bulls having closer median distances to equestrian trails while in preferred cover types (i.e., regenerating aspen, openings, northern hardwoods; See RESULTS, Chapter 3), we do not believe the absence of GPS-collared elk from areas with recreation events in the PRC during September was due to elk avoiding areas with recreational trails. Additionally, we found no changes in elk selection of areas for home ranges in response to increased recreational intensity (See RESULTS, Chapter 3). We did find that areas within 60 m of an equestrian trail in the PRC had lower habitat suitability (0.215) than the mean habitat suitability of elk home ranges (cows = 0.406, bulls = 0.323) and for the entire PRC (0.254) (See DISCUSSION, Chapter 3; Figure 4.7). Thus, we believe the absence of GPS-collared elk from areas with equestrian trails in the PRC was likely due to elk not using areas with lower habitat suitability.

Although our lack of responses from a cow elk in the PRC during 4 encounters with equestrian users suggests that equestrian use may not elicit behavioral responses from elk within the distances they occurred from trails, the small sample size does not provide sufficient data to evaluate our predictions. Furthermore, the cow elk was in a different cover type (i.e., openings, northern hardwoods, regenerating aspen, upland conifers) during each encounter, which likely provided varying amounts of horizontal cover that has been found to partially mitigate the negative responses of elk and red deer (*Cervus elaphus*) from interactions with humans (Lyon 1983, Sibbald et al. 2011, Wisdom et al. 2018). For example, the only encounter we recorded within the mean flight distance (60 m) for elk in Michigan had an encounter distance of 42 m with the cow being in a mature (80-89 years-old) northern hardwoods stand with hardwoods regeneration in the understory that likely provided horizontal cover (Table 4.2). In contrast, the only encounter between the cow and equestrian users with no cover occurred in an opening at a distance of 114 m, which was nearly 2 times the mean flight distance (60 m) of elk in Michigan. Thus, ample horizontal cover may have prevented elk responses during the 3 encounters that were closest to equestrian users (42 m in northern hardwoods, 86 m in regenerating aspen, 92 m in upland conifers).

Our lack of encounters between equestrian users and elk in the ASF was likely due, in part, to our findings for greater recreational intensity by equestrian users in the PRC than the ASF (See RESULTS, Chapter 2). In September 2018, recreational intensity of equestrian users was

6.6 times greater in the PRC than the ASF (See Tables 2.4 and 2.10, Chapter 2). During conversations with volunteers at the public equestrian users meeting on 28–September, 2018, users communicated their preference for riding in the PRC due to the group camping experience (i.e., a minimum of 10 people per group with a maximum campground capacity of 100 individuals) and variety of amenities (e.g., fire rings, tables, toilets, potable water, and manure bunkers). We attribute the disparity in equestrian use participation in our experimental events between regions to less equestrian use in the ASF and an abundance of equestrian groups (i.e., Pigeon River Country Equestrian Committee, Tri-County Horse Association, and Alpena County Horseman's Club) in the PRC.

Our lack of volunteer participation from mountain bikers in both regions was primarily due to a relative lack of use in the PRC and ASF during our study events. Although mountain biking intensity was greater during September than May–August, intensity of equestrian use was 37 times greater than mountain biking in the PRC and 11 times greater in the ASF (See Tables 2.4 and 2.10, Chapter 2). During conversations with mountain bikers in July of 2018, 6 of 7 volunteer contacts commented that use of the PRC was rare and inconsistent due to riding elsewhere. Although there are approximately 78 km of mountain biking trails in the PRC, the Michigan Division of Parks and Recreation provides approximately 2,250 km of mountain biking trails statewide (MDNR 2018). Notably, there is a 100 km rail trail (North Central State Trail) that is within 1 km of Interstate-75, which mountain bikers would need to pass if traveling to the PRC from Interstate-75. Thus, interactions between mountain bikers and elk in the PRC and ASF are likely to be infrequent and less common than interactions between equestrian users and elk due to the abundance of opportunities for riding elsewhere.

Despite our lack of encounters between recreational users and GPS-collared elk, 18% of equestrian user event participants reported seeing at least 1 elk that was not collared. Notably, we participated in an equestrian use event on 28–September, 2018, during which we observed an uncollared bull elk feeding in an opening approximately 100 m from the forest road that we used. The bull elk did not flee during the encounter with 6 equestrian users and 2 dogs. However, we observed a car using the forest road < 5 minutes after our encounter, which elicited a flight response from the bull. Although anecdotal, our observation was consistent with other reported sightings by equestrian users during our events. In a similar study in Oregon, elk demonstrated some evidence of habituation to equestrian use but not mountain biking, hiking, or ATV use (Naylor et al. 2009). Although our limited results and observations of no changes in elk behavior or movements in response to encounters with equestrian users during our study suggest that elk in the PRC may have a tolerance to the consistent presence of equestrian users, we caution against using results limited to 4 encounters with 1 cow in the PRC and anecdotal reports and observations.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The processes we used to develop and integrate habitat suitability and habitat potential models demonstrated a multifocal approach for understanding the spatiotemporal dynamics of wildlife habitat. While each model provides a different lens to examine the habitat value for elk, we believe the integration of habitat suitability and habitat potential models provides added value for managers. A primary advantage in the simultaneous use of these models is the ability for managers to identify areas with low habitat suitability and high habitat potential to determine which areas will respond to management treatments by providing habitat life requisites for elk. Areas with high suitability can be managed to remain suitable, and areas with low suitability and high potential can be managed to provide high suitability in later years. For example, mature aspen stands have low habitat suitability for winter and spring food due to the inability of elk to reach browse, but have high potential for food if they are clearcut to promote regeneration. Although elk managers in Michigan currently manage for elk food by promoting regeneration through harvesting mature stands and maintaining the proportion of aspen for no net loss, the selection of stands that are cut may be important for managing the spatial distribution of elk within the PRC and ASF. Selecting mature aspen for harvest in areas near the core of the PRC and ASF instead of the boundary near private lands may reduce elk movements beyond the designated elk range. Areas with low habitat potential for elk, especially near the edges of the range, could become focal areas to meet other wildlife management goals or land uses (e.g., recreation opportunities). We also recommend consideration of clearcuts that are greater in size than the current 0.16 km^2 (40-acre) harvest size limitation found in the PRC's COM. Clear-cuts greater than 0.16 km^2 in size may be more likely to regenerate successfully by dispersing elk browsing throughout the area.

Our findings of consistent temporal patterns of recreational intensity by month, day of week, and time of day in the PRC and ASF suggests that managers may be able to develop land management strategies irrespective of recreational use regulations. For example, managers desiring to provide recreational opportunities for specific recreation types (e.g., equestrian use, ORV use) can expect similar patterns of weekend and mid-day use regardless of target user type. Designating trail use for specific types and maintenance or enhancements of existing trail systems (e.g., PRC) may directly affect recreational intensity and influence which types of recreation are likely to occur. We encourage natural resource managers to consider trail attributes (e.g., proximity to camping areas) and amenities (e.g., potable water) when developing land use plans involving management of recreational use patterns. For example, providing horse-related amenities such as manure bunkers in camping areas near designated equestrian trails will likely result in increased intensity of use and spatial partitioning of equestrian users to those areas. Conversely, multi-use trails, off-trail riding, and a lack of amenities will likely disperse users across the landscape but result in less recreational use (e.g., ASF). Understanding the intensity, temporal patterns, and spatial extent of recreational users on public lands is vital for managers attempting to achieve multiple management objectives for long-term sustainable use and recreational opportunities. For example, managers could provide trail enhancements and user amenities to focus or re-direct recreational use to areas where other management objectives (e.g., wildlife habitat enhancement, timber management) are less of a priority. State agencies may be able to use the presence or absence of recreational use regulations (e.g., designated trails) and amenities to market different potential recreational experiences for the public. Areas with a well-developed system of designated trails in close proximity to user-related amenities (e.g., PRC) could be marketed to new outdoor recreational users of the area, or those users looking for a more comfortable and group-friendly experience, while areas that permit off-trail use without amenities (e.g., ASF) may be marketed to users that desire a more primitive or less structured experience. We recommend that future research focus on other recreation types (e.g., snowmobiling, cross-country skiing) occurring during winter and early spring months when elk and other species may be nutritionally stressed to further evaluate and compare recreational use patterns under differing regulations, and evaluate potential impacts to wildlife populations, communities, and habitat. Consideration of user preferences for multiple user groups is vital for natural resources managers attempting to understand and manage the intensity, temporal patterns, and spatial extent of recreational use on public lands while conserving natural resources for other management objectives.

Increasing participation of trail-based recreational activities creates challenges and opportunities for wildlife and land managers attempting to achieve multiple management objectives on public lands around the world. Our findings indicated some changes in home-range scale space-use patterns and proportional use of habitat components of elk in response to periods of relatively greater intensity of ORV use. Although we found little evidence to suggest trail-based recreational activity is having direct or indirect negative effects on the Michigan elk herd, we attribute our findings to wildlife managers creating an abundance and interspersion of cover types providing high habitat suitability throughout the elk range. Designating areas for specific types of trail use provides managers opportunities to limit negative human-wildlife interactions spatially and temporally. Although we found little evidence that summer trail-based recreation had any effects on elk space-use and resource selection in the PRC, we suggest managers alternate use of connector trails seasonally to reduce the frequency and volume of interactions to decrease the potential for impacts due to future changes in recreational intensity or types of use.

For example, temporarily closing a mountain biking or equestrian trail that travels through or within close proximity to an opening during late-spring (April–May), would likely limit late-morning or early-evening interactions between elk and mountain bikers or equestrian users. Concurrently, alternate trails that travel through hardwood or conifer stands could be opened during late-spring to provide new opportunities for trail users that reduce the likelihood of interactions with elk. Although these recommendations seek to limit negative interactions between elk and recreational users, objectives for providing elk viewing opportunities could be achieved by establishing elk viewing areas at strategic trail locations such as near large openings that would limit numerous encounters leading to disturbances of elk. Habitat and user management strategies that limit negative interactions between elk and trail-based recreational users will maintain long-term sustainability of elk, quality habitat, and diverse recreational opportunities for the future. We also recommend periodic monitoring of all recreation types in the elk range to identify potential changes in the types, patterns, and cumulative effects of use in the future. According to the most recent (22-April, 2021) meeting minutes of the Pigeon River Country Advisory Council, use of campgrounds and areas for recreational use was greater in spring 2021 than previous years and the trend of increasing use is expected to continue in the future (PRCAC 2021). Although we found very few ORV users in the PRC during our study (i.e., 74 events), recent discussions with MDNR personnel revealed that conservation officers are using ORVs to monitor illegal ORV use in the PRC. Thus, intensity of ORV use in the PRC has likely increased since the completion of data collection period in 2018.

Although we demonstrated consistent use of the PRC’s designated equestrian trails during September 2018, the absence of collared elk from areas with equestrian use and mountain biking events during our trials limited our results to 4 encounters between elk and equestrian users. Our limited results showing elk tolerance for equestrian use was consistent with findings in other research. Based on our limited results being consistent with other research for encounters between elk and equestrian users and other research demonstrating negative elk responses to mountain biking and ORV use, we believe natural resource managers can use the varying responses of elk to different types of recreation when managing recreational use on public lands. For example, designated trails for ORV use and mountain biking may be placed, managed, and promoted in areas with low habitat potential to decrease the frequency of negative interactions with elk. Although we do not recommend placing equestrian trails in areas of high elk habitat suitability, areas of medium suitability may be considered to increase opportunities for wildlife viewing and limit the potential for negative effects to elk. Although we found no evidence of elk responses to equestrian or mountain biking events, we caution against drawing conclusions based on our experimental recreation results and observations. We recommend future research that focuses on quantifying and comparing elk responses to a greater variety of recreation types (e.g., ORV use, snowmobiling) that have been found to have different effects on elk and other large ungulates. We also recommend monitoring recreation events throughout the year to monitor elk responses to recreational activity during different seasons. For example, monitoring snowmobiling during winter when horizontal cover is limited and elk are more nutritionally stressed may provide insights on the value of hiding cover for elk during encounters with recreational users. Identifying differences in how elk respond to a variety of recreation types throughout the year would inform wildlife managers attempting to develop elk habitat management strategies and predict population responses.

APPENDICES

APPENDIX A

Elk Collaring and Capture Data

Table A1. Elk collaring and capture data from 3 capture events in the Pigeon River Country (PRC) and Atlanta State Forests (ASF) from 15–16 February, 2016, 9–April, 2017, and 22–February, 2018.

Collar ID	Collar frequency	Ear tag	Capture date	Site	Latitude	Longitude	Sex	Age[2]	BC score[3]	Samples			Antibiotic injection[4]
										Blood	Fecal	Hair	
20172	150.010	77	2/15/16	PRC	45.17597	-84.37998	Cow	A	4	Y	Y	Y	Y
20173	150.070	78	2/16/16	ASF	45.08769	-84.30280	Cow	A	NA	Y	Y	Y	N
20174	150.200	54	2/16/16	ASF	45.10657	-84.33894	Bull	A	4	Y	Y	Y	Y
20175	150.270	86	2/16/16	ASF	45.10610	-84.31988	Cow	A	4.5	Y	Y	Y	Y
20176	150.310	80	2/15/16	PRC	45.20316	-84.39331	Bull	Y	7	N	N	N	N
20177	150.330	88	2/15/16	PRC	45.20944	-84.35055	Bull	A	3	Y	Y	Y	Y
20177b[1]	150.330	127/128	4/09/17	ASF	45.08429	-84.35522	Bull	A	2	Y	Y	Y	Y
20178	150.360	66	2/15/16	PRC	45.07901	-84.41920	Cow	NA	4.5	Y	Y	Y	Y
20179	150.420	52	2/16/16	ASF	45.08781	-84.32435	Cow	A	4	Y	Y	Y	Y
20180	150.440	79	2/16/16	ASF	45.09666	-84.34527	Bull	NA	NA	Y	Y	Y	Y
20181	150.460	69	2/16/16	ASF	45.08746	-84.32471	Bull	A	4.5	Y	Y	Y	Y
20182	150.490	68	2/16/16	PRC	45.22780	-84.43920	Bull	A	4	Y	Y	Y	N
20182b[1]	150.490	107/124	2/22/18	PRC	45.06119	-84.23547	Bull	A	3.5	Y	Y	Y	Y
20183	150.510	89	2/16/16	ASF	45.08611	-84.30277	Bull	NA	3	Y	Y	Y	N
20184	150.530	70	2/16/16	ASF	45.10431	-84.33684	Bull	Y	4.5	Y	Y	Y	N
20185	150.570	75	2/15/16	PRC	45.10407	-84.37108	Cow	A	4	Y	Y	Y	N
20186	150.590	59	2/15/16	PRC	45.20186	-84.39114	Cow	Y	3	Y	Y	Y	N
20187	150.610	81	2/16/16	PRC	45.08733	-84.38811	Bull	Y	3	Y	Y	Y	N
20188	150.640	64	2/16/16	ASF	45.10521	-84.33646	Cow	A	4	Y	Y	Y	Y
20189	150.660	61	2/15/16	PRC	45.10440	-84.37095	Cow	A	3.5	Y	Y	Y	Y
20190	150.690	83	2/16/16	PRC	45.17944	-84.51417	Bull	A	NA	Y	Y	Y	N
20191	150.730	60	2/15/16	PRC	45.12155	-84.39676	Cow	A	4	Y	Y	Y	Y
20192	151.100	71	2/16/16	ASF	45.10600	-84.33600	Bull	Y	2.5	Y	Y	Y	Y
20193	151.120	56	2/16/16	ASF	45.10536	-84.33824	Bull	NA	4	Y	Y	Y	Y
20194	151.140	84	2/16/16	ASF	45.08710	-84.30396	Cow	A	4.5	Y	Y	Y	Y
20194b[1]	151.140	139/140	2/22/18	PRC	45.22634	-84.43938	Cow	A	3.5	Y	Y	Y	Y
20195	151.160	90	2/16/16	ASF	45.08710	-84.30396	Bull	NA	4	Y	Y	Y	Y
20196	151.190	72	2/15/16	PRC	45.07870	-84.41810	Bull	Y	4	Y	Y	Y	N

Table A1. (cont'd)

20197	151.210	82	2/15/16	PRC	45.10411	-84.37133	Cow	A	5	Y	Y	Y	Y
20197b[1]	151.210	105/106	2/22/18	ASF	45.08611	-84.30297	Cow	A	4	Y	Y	Y	Y
20198	151.280	87	2/15/16	PRC	45.12200	-84.39512	Cow	NA	5	Y	Y	Y	Y
20199	151.360	74	2/16/16	ASF	45.10411	-84.33537	Bull	Y	3	Y	Y	Y	Y
20200	151.450	57	2/16/16	ASF	45.10561	-84.31893	Cow	NA	4.5	Y	Y	Y	Y
20201	151.490	73	2/16/16	PRC	45.19777	-84.44694	Bull	NA	3	Y	Y	Y	N
20202	151.520	58	2/16/16	ASF	45.10518	-84.33632	Bull	Y	4	Y	Y	Y	Y
20203	151.560	76	2/16/16	ASF	45.08718	-84.30396	Cow	A	5	Y	Y	Y	Y
20204	151.590	85	2/16/16	ASF	45.08673	-84.30253	Bull	NA	4	Y	Y	Y	Y
20205	151.630	55	2/16/16	ASF	45.10442	-84.33601	Cow	A	3.5	Y	Y	Y	Y
20206	151.660	51	2/15/16	PRC	45.20165	-84.39032	Cow	A	4.5	Y	Y	Y	Y
20207	151.690	62	2/16/16	ASF	45.08762	-84.30214	Bull	Y	4	Y	Y	Y	Y
20419	151.720	63	2/16/16	ASF	45.10681	-84.32018	Cow	A	4.5	Y	Y	Y	Y
20419b[1]	151.720	092	2/22/18	ASF	45.08791	-84.30495	Cow	A	4	Y	Y	Y	Y
20420	151.760	67	2/16/16	ASF	45.08750	-84.30444	Bull	A	3	Y	Y	Y	N
20421	151.790	65	2/15/16	PRC	45.20176	-84.39057	Cow	A	4	N	Y	Y	Y
20422	151.830	53	2/15/16	PRC	45.07737	-84.41600	Cow	Y	2	Y	Y	Y	Y
23364	151.680	097	2/22/18	ASF	45.08636	-84.29931	Cow	A	4	Y	Y	Y	Y
29865	150.040	098	2/22/18	ASF	45.08597	-84.30271	Cow	A	4	Y	Y	Y	Y
29866	150.100	141/142	2/22/18	PRC	45.10241	-84.39116	Bull	A	3	Y	Y	Y	Y
29867	150.170	133/134	2/22/18	PRC	45.22562	-84.43699	Bull	A	4	Y	Y	Y	Y
29868	150.770	100	2/22/18	PRC	45.17760	-84.40125	Bull	A	2.5	Y	Y	Y	Y
29869	150.830	093	2/22/18	PRC	45.22626	-84.43648	Cow	A	3.5	Y	Y	Y	Y
29871	150.910	135/136	2/22/18	PRC	45.10060	-84.39149	Bull	A	3.5	Y	Y	Y	Y
29872	150.870	091	2/22/18	ASF	45.08691	-84.29824	Cow	A	4	Y	Y	Y	Y

[1] Collar was collected following mortality and refurbished before being placed on elk.

[2] Age was categorized as either adult (A) or yearling (Y).

[3] A visual body condition score (BC) was used to evaluate the status and condition of the elk (Gerhart et al. 1996).

[4] Elk were given intramuscular antibiotic (Flocillin, Bristol Laboratories, Syracuse, N.Y.) injections to minimize risk of infection.

APPENDIX B

Elk Collar Events History

Collar Deployments, Elk Mortalities, Collar Failures, Collar Retrievals

Table B1. Elk collar events history (i.e., collar deployments, elk mortalities, collar failures, collar retrievals) in northern lower Michigan from 15–February, 2016 to 2–February, 2020.

Collar ID	Deployment date	Retrieval[1] date	Elk Mortality Date	Elk Mortality Cause	Collar Failure Date	Collar Failure Notes
20172	02/15/2016				04/10/2017	Stopped providing GPS fixes
20173	02/16/2016	12/10/2017	12/10/2017	Hunter harvest	05/31/2016	Stopped providing GPS fixes
20174	02/16/2016				05/01/2017	Stopped providing GPS fixes
20175	02/16/2016				03/07/2018	Stopped providing GPS fixes
20176	02/15/2016	02/13/2019				
20177	02/15/2016	04/03/2016	03/30/2016	Meningeal worm[2]		
20177b	04/09/2017	02/13/2019			09/18/2018	Stopped providing GPS fixes
20178	02/15/2016	02/13/2019				
20179	02/16/2016	02/12/2019				
20180	02/16/2016				02/12/2018	Stopped providing GPS fixes
20181	02/16/2016				09/25/2017	Stopped providing GPS fixes
20182	02/16/2016	10/01/2016	10/01/2016	Hunter harvest	09/27/2016	Stopped providing GPS fixes
20182b	02/22/2018	02/13/2019				
20183	02/16/2016	02/13/2019				
20184	02/16/2016	02/12/2019				
20185	02/15/2016	01/03/2018	01/03/2018	Hunter harvest	06/25/2017	Stopped providing GPS fixes
20186	02/15/2016	02/12/2019				
20187	02/16/2016	12/16/2018	12/16/2018	Hunter harvest		
20188	02/16/2016	01/12/2019			01/15/2019	Stopped providing GPS fixes
20189	02/15/2016				07/17/2018	GPS fixes were very intermittent
20190	02/16/2016				11/30/2018	Stopped providing GPS fixes
20191	02/15/2016	02/12/2019				
20192	02/16/2016	12/11/2017	12/11/2017	Hunter harvest		
20193	02/16/2016	02/12/2019				
20194	02/16/2016	12/10/2016	12/10/2016	Illegal kill[3]		
20194b	02/22/2018	02/17/2020			04/25/2019	Stopped providing GPS fixes
20195	02/16/2016				09/01/2018	Stopped providing GPS fixes
20196	02/15/2016	02/12/2019				

Table B1. (cont'd)

20197	02/15/2016	12/10/2016	12/10/2016	Hunter harvest		
20197b	02/22/2018	02/13/2019				
20198	02/15/2016	02/13/2019				
20199	02/16/2016	02/13/2019				
20200	02/16/2016				09/23/2018	Stopped providing GPS fixes
20201	02/16/2016				09/27/2018	Stopped providing GPS fixes
20202	02/16/2016				02/23/2017	Stopped providing GPS fixes
20203	02/16/2016	12/15/2018	12/15/2018	Hunter harvest	04/04/2017	Stopped providing GPS fixes
20204	02/16/2016	12/17/2018	12/17/2018	Hunter harvest	06/04/2018	Stopped providing GPS fixes
20205	02/16/2016	02/12/2019				
20206	02/15/2016				11/16/2017	Stopped providing GPS fixes
20207	02/16/2016	02/12/2019				
20419	02/16/2016	12/10/2016	12/10/2016	Illegal kill[3]		
20419b	02/22/2018	02/13/2019	12/26/2020	Hunter harvest		
20420	02/16/2016	12/19/2018	12/19/2018	Hunter harvest		
20421	02/15/2016	02/13/2019				
20422	02/15/2016	02/12/2019				
23364	02/22/2018	03/06/2018	02/23/2018	Capture related[4]		
29865	02/22/2018	02/13/2019			02/28/2019	Stopped providing GPS fixes
29866	02/22/2018	02/13/2019				
29867	02/22/2018	02/13/2019				
29868	02/22/2018	02/13/2019			04/26/2019	Stopped providing GPS fixes
29869	02/22/2018	02/13/2019				
29871	02/22/2018	02/13/2019				
29872	02/22/2018	02/13/2019				

[1] Collars were collected following mortality events or after programmed drop-off on 15–January, 2019.

[2] Mortality due to meningeal worm was confirmed by Michigan Department of Natural Resources (MDNR) wildlife biologist specialist and pathologist Thomas M. Cooley.

[3] Illegal kills were confirmed by MDNR biologists and conservation officers.

[4] Cow elk was determined to have died of capture-related causes the day following capture and collaring. A field examination by Chad Williamson revealed internal bleeding.

APPENDIX C

Experimental Recreation Use Events

Table C1. Experimental equestrian use and mountain biking events monitored with handheld GPS receivers in the Pigeon River Country (PRC) and Atlanta State Forests (ASF) from 31–August to 30–September, 2018.

Date	Event type	Region	Group size	Start time	End time	Duration	Distance (km)	Speed (kph)	Elk sighting	Volunteer/notes
8/31/2018	Equestrian	PRC	3	10:07	13:37	3:30	12.71	3.63	Yes	
8/31/2018	Equestrian	PRC	2	10:08	14:37	4:29	12.07	2.69		
8/31/2018	Equestrian	PRC	3	10:09	12:41	2:32	6.92	2.73		
8/31/2018	Equestrian	PRC	3	11:30	14:20	2:50	11.75	4.15		
8/31/2018	Equestrian	PRC	3	14:50	16:46	1:56	6.92	3.58		
8/31/2018	Equestrian	PRC	3	18:08	20:03	1:55	8.37	4.37		
9/1/2018	Equestrian	PRC	1	8:32	13:57	5:25	21.24	3.92	Yes	
9/1/2018	Equestrian	PRC	2	10:16	13:16	3:00	12.39	4.13		
9/1/2018	Equestrian	PRC	5	10:30	12:35	2:05	7.72	3.71	Yes	
9/1/2018	Mtn. Biking	ASF	3	10:42	11:37	0:55	6.92	7.55		Jeffrey [a]
9/1/2018	Mtn. Biking	ASF	3	12:00	12:34	0:34	4.35	7.67		Jeffrey [a]
9/1/2018	Equestrian	PRC	5	12:05	15:15	3:10	12.71	4.01		
9/2/2018	Equestrian	PRC	2	8:18	13:54	5:36	20.60	3.68		
9/2/2018	Equestrian	PRC	2	8:47	11:25	2:38	12.23	4.64	Yes	
9/2/2018	Equestrian	PRC	2	9:07	11:45	2:38	11.43	4.34		
9/2/2018	Equestrian	PRC	4	12:20	13:52	1:32	5.79	3.78		
9/2/2018	Equestrian	PRC	3	12:29	15:12	2:43	9.50	3.50		
9/3/2018	Equestrian	PRC	2	7:49	10:37	2:48	11.75	4.20	Yes	
9/3/2018	Equestrian	PRC	2	10:13	16:03	5:50	24.14	4.14		
9/3/2018	Equestrian	PRC	3	10:23	11:45	1:22	6.76	4.95		
9/17/2018	Equestrian	PRC	2	11:13	13:00	1:47	8.53	4.78		
9/18/2018	Equestrian	PRC	2	11:48	14:11	2:23	11.43	4.79	Yes	
9/19/2018	Equestrian	PRC	2	9:52	12:18	2:26	10.62	4.37		
9/19/2018	Equestrian	PRC	2	18:38	19:29	0:51	3.38	3.98		
9/21/2018	Equestrian	ASF	9	18:35	20:05	1:30	6.28	4.18		Chuck and family
9/22/2018	Equestrian	ASF	12	18:40	20:21	1:41	5.95	3.54	Yes	Chuck and family
9/25/2018	Equestrian	PRC	5	9:31	13:07	3:36	15.61	4.34		
9/25/2018	Equestrian	PRC	2	10:08	13:44	3:36	18.02	5.01		

Table C1. (cont'd)

9/25/2018	Equestrian	PRC	2	10:20	13:28	3:08	17.54	5.60		
9/25/2018	Equestrian	PRC	1	14:56	15:41	0:45	3.86	5.15		+ 2 dogs
9/25/2018	Equestrian	PRC	5	18:40	19:54	1:14	6.44	5.22		
9/26/2018	Equestrian	PRC	3	9:54	11:32	1:38	8.85	5.42	Yes	
9/26/2018	Equestrian	PRC	2	11:51	13:55	2:04	9.33	4.52		
9/26/2018	Equestrian	PRC	2	12:26	16:46	4:20	15.61	3.60		
9/26/2018	Equestrian	PRC	2	13:26	16:01	2:35	10.14	3.92		Jeff and Christine
9/26/2018	Equestrian	PRC	3	14:18	17:16	2:58	19.15	6.46		
9/26/2018	Equestrian	PRC	3	14:57	16:17	1:20	7.56	5.67		Jane
9/26/2018	Equestrian	PRC	2	15:08	16:17	1:09	4.83	4.20		
9/26/2018	Equestrian	PRC	3	18:55	19:39	0:44	3.70	5.05		
9/27/2018	Equestrian	PRC	2	7:43	9:14	1:31	6.44	4.24		Jeff and Christine
9/27/2018	Equestrian	PRC	6	10:42	14:20	3:38	18.51	5.09		
9/27/2018	Equestrian	PRC	6	11:05	14:23	3:18	17.54	5.32	Yes	
9/27/2018	Equestrian	PRC	3	15:11	15:55	0:44	3.54	4.83		
9/27/2018	Equestrian	PRC	2	16:59	19:47	2:48	10.94	3.91		
9/27/2018	Equestrian	PRC	2	17:48	19:45	1:57	9.50	4.87		Jeff and Christine
9/27/2018	Equestrian	PRC	3	18:11	19:41	1:30	8.69	5.79		
9/27/2018	Equestrian	PRC	4	18:38	19:11	0:33	2.90	5.27		
9/28/2018	Equestrian	PRC	2	8:14	11:07	2:53	11.10	3.85		Jane
9/28/2018	Equestrian	PRC	3	14:40	17:33	2:53	14.64	5.08		
9/28/2018	Equestrian	PRC	4	15:23	17:15	1:52	9.50	5.09		
9/28/2018	Equestrian	PRC	6	15:32	17:05	1:33	6.44	4.15	Yes	Darlene + 2 dogs [a]
9/28/2018	Equestrian	PRC	1	16:10	18:31	2:21	9.33	3.97		+ 2 dogs
9/28/2018	Equestrian	PRC	2	16:24	19:01	2:37	11.27	4.31		Jane
9/28/2018	Equestrian	PRC	2	17:31	19:18	1:47	6.60	3.70		
9/28/2018	Equestrian	PRC	2	17:34	19:48	2:14	9.98	4.47	Yes	Jeff and Christine
9/28/2018	Equestrian	PRC	3	17:45	19:48	2:03	9.98	4.87		
9/29/2018	Equestrian	PRC	2	9:26	15:41	6:15	24.94	3.99		Jane
9/29/2018	Equestrian	PRC	2	9:43	13:21	3:38	18.02	4.96	Yes	
9/29/2018	Equestrian	PRC	2	9:49	13:34	3:45	17.70	4.72		
9/29/2018	Equestrian	PRC	5	10:25	13:26	3:01	14.81	4.91		

Table C1. (cont'd)

9/29/2018	Equestrian	PRC	6	11:10	12:19	1:09	5.15	4.48		Darlene + 2 dogs
9/29/2018	Equestrian	PRC	3	11:17	14:07	2:50	13.04	4.60		
9/29/2018	Equestrian	PRC	6	12:32	15:37	3:05	14.32	4.65		Darlene + 2 dogs
9/29/2018	Equestrian	PRC	1	14:36	15:37	1:01	4.67	4.59		
9/29/2018	Equestrian	ASF	2	15:41	19:09	3:28	16.25	4.69	Yes	Marv and Donna
9/29/2018	Equestrian	PRC	3	16:50	18:45	1:55	10.30	5.37		
9/29/2018	Mtn. Biking	PRC	2	16:55	18:52	1:57	13.04	6.68		Jeffrey
9/29/2018	Equestrian	PRC	2	17:03	20:07	3:04	13.20	4.30	Yes	
9/30/2018	Equestrian	ASF	2	8:23	12:07	3:44	10.30	2.76	Yes	Marv and Donna
9/30/2018	Equestrian	PRC	2	8:31	10:45	2:14	8.69	3.89		Jane
9/30/2018	Equestrian	PRC	2	9:00	10:21	1:21	7.24	5.36		
9/29/2019	Equestrian	PRC	2	11:15	13:37	2:22	10.30	4.35		Jeff and Christine

[a] Chad Williamson participated

APPENDIX D

Metadata

Data for this project was stored on 2 external hard drives and a desktop computer. In each location, a master folder titled "MSU_Elk_ Rec_Project" contains 6 subfolders containing raw data files (e.g., .csv, .docx, .pdf) and data analysis files (e.g., .R) . Those folders are:

1) "1–Elk Habitat Suitability and Potential"

   This folder contains a subfolder titled "Habitat_Analysis" which contains subfolders titled "HABITAT_SUITABILITY" and "HABITAT_POTENTIAL" that contain all raw data files and ArcGIS files used to quantify habitat suitability and potential for Chapter 1.

2) "2–Trail-Based Recreation in the Elk Range"

   This folder contains a subfolders titled "Recreation_Data" and "Human_Rec_Analyses". The "Recreation_Data" folder contains 3 subfolders (ie.., "2016", "2017", "2018") that each contain trail camera images that were used to quantify recreational intensity described in Chapter 2, METHODS and RESULTS. The "Human_Rec_Analyses" folder contains raw data files and R script files used to create the generalized linear model and perform the statistical analyses described in METHODS for Chapter 2.

3) "Elk Space-Use and Resource Selection"

   This folder contains subfolders titled "Movement_Analyses" and "Resource_Selection". The "Movement_Analyses" folder contains subfolders (e.g., "dBBMM", "Distance_roads_trails", "Home_Range_Analysis") containing raw data files and R script files for the elk space-use analyses described in Chapter 3, METHODS and RESULTS. The "Resource_Selection" folder contains subfolders titled "dBBMM_habitat_selection" and "Landscape_scale_resource_selection" that contain raw data files and R script files for the elk resource selection analyses described in Chapter 3, METHODS and RESULTS.

4) “Elk Behavior in Response to Recreation Events”

   This folder contains subfolders titled “Field_Trial_Data” and “Field_Trial_Anlaysis”. The “Field_Trial_Data” and “Field_Trial_Analysis” folder contains raw data files and R script files for the recreation events and analyses described in Chapter 4, METHODS and RESULTS.

5) “ArcGIS”

   This folder contains the primary .mxd file titled “Elk_Project_MSU_10.3” and subfolders containing raw data and .shp files used for all analyses in ArcGIS.

6) “Elk_Collar_Data”

   This folder contains the primary database file “Elk Collar Database with Capture Data” containing the elk capture data, and subfolders containing raw data files for elk locations and mortality events. The master data file for all locations is located in the “Location_Data” subfolder and is titled “MASTER_LOCATION_DATA”.

APPENDIX E

Outreach and Presentation Experience

I attended 17 professional conferences, meetings, and events to promote awareness and community engagement with my project focusing on elk responses to habitat potential and human recreation use in the Michigan elk range (Table E1). During these meetings and events, I presented project objectives, methods and updates regarding findings, plans, project timelines, and potential management implications and answered questions related to research project activities and use of information to guide elk management. In 2017, I conducted a children's interactive outreach presentation (i.e., facilitated by Alpena Community College and US Fish and Wildlife Service Outdoor Education Program) at Clear Lake State Park, MI. In 2018, I led an interactive hike and presentation for Michigan Governor Rick Snyder and family (i.e., facilitated by MDNR) at the Pigeon River Country State Forest, MI. Additionally, I participated in recreational activities (e.g., horseback riding, mountain biking) during August of 2018 with user groups to promote study activities (e.g., monitoring elk responses to human recreation use along trails and forest roads) and better understand the types of recreation data (e.g., duration and distance of rides, group size, time of day) being collected during our study. I also developed a research project Facebook page (i.e., no longer active), which was transitioned to a MSU project website (https://www.canr.msu.edu/msuelk/) to provide access to project updates, results, and conclusions.

Table E1. Professional conferences, meetings, and events attended to promote awareness and community engagement with my project focusing on elk responses to habitat potential and human recreation use in the Michigan elk range, from 2016–2020.

Year	Presentation/Seminar title	Conference/Meeting/Event, location
2020	Collared elk locations during 2016–2018	MDNR[1] elk working group meeting, Gaylord, MI
2019	Elk responses to recreational use and habitat potential in Michigan	Tri-County Horse Association meeting, Freeland, MI
2019	Elk habitat suitability and potential of public and private lands in MI	Michigan Fish and Wildlife Conference, Gaylord, MI
2019	Elk responses to recreational use and habitat potential in Michigan	PRCEC[2] quarterly meeting, Roscommon, MI
2019	Elk habitat suitability and potential of public and private lands in MI	Midwest Fish and Wildlife Conference, Cleveland, OH
2018	Elk responses to recreational use and habitat potential in Michigan	PRCEC[2] quarterly meeting, Roscommon, MI
2018	Current elk habitat suitability of public and private lands in Michigan	Eastern Elk Management Workshop, Lewiston, MI
2017	Quantifying elk habitat suitability and potential in the MI elk range	PRCEC[2] quarterly meeting, Roscommon, MI
2017	Elk responses to recreational use and habitat potential in Michigan	Montmorency County Conservation Club meeting, Atlanta, MI
2017	Elk responses to recreational use and habitat potential in Michigan	PRCEC[2] quarterly meeting, Roscommon, MI
2017	Elk responses to recreational use and habitat potential in Michigan	MSU FW GSO Student Symposium, East Lansing, MI
2016	Elk responses to recreational use and habitat potential in Michigan	MDNR[1] Wildlife Division annual meeting, Roscommon, MI
2016	Elk responses to recreational use and habitat potential in Michigan	PRCEC[2] quarterly meeting, Roscommon, MI

[1] Michigan Department of Natural Resources
[2] Pigeon River Country Equestrian Committee

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