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Research Article

Estimating encounter probabilities among recreational trail user groups

Shelby McCahon [a,*], Todd Brinkman [a], Ryan Klimstra [b]

[a] Department of Biology and Wildlife, University of Alaska Fairbanks, Fairbanks, AK, USA
[b] Alaska Department of Fish and Game, Fairbanks, AK, USA

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ABSTRACT

The global rise in nature-based recreation increases the need for research on visitor activity use and interaction especially for multi-use trail systems. Conflict often arises during negatively perceived physical encounters (i.e., direct observation) of different user groups. Our study addresses these encounters on a winter multi-use refuge in Fairbanks, Alaska. Our goal was to develop a method that generates spatially and temporally explicit estimates of trail occupancy and encounter probabilities among different user groups. We used trail cameras with optic alteration to protect individual identity. We monitored winter recreational activity from November 2019 to April 2020 ($n = 133$ days) and sorted users into three user groups: 1) motor-powered, 2) dog-powered, and 3) human-powered. We calculated the total number of occurrences and proportion of activity across all user groups at each camera location. We identified hotspots of activity overlap (e.g., near trail access points), and peak times (14:01–15:00), days (Saturdays and Sundays), and months (December, February, and March) that may have had higher potential for physical encounters and conflict. We used multiplication and addition probability rules to estimate two probabilities: 1) the probability of user groups occupying individual trail segments, and 2) the probability of encounter between different user groups. We scaled up these probability estimates both temporally (hourly and daily) and spatially (refuge quadrant and refuge-wide). Researchers can adapt our novel method to any recreational trail system to identify locations with potential for congestion and conflict. This method can help inform management that improves visitor experience and overall trail user satisfaction.

Management implications: We provide managers of recreational trail systems with a quantitative, objective, and noninvasive method to monitor activity among trail user groups. This method can be altered both spatially and temporally to fit any recreational trail system's research questions. These questions may involve congestion, trail carrying capacity, or user group and wildlife encounters. Our method advances current knowledge of trail use dynamics by quantifying the extent of activity overlap between different user groups that may be prone to conflict. Managers can use this information to incorporate relevant management strategies to mitigate congestion and conflict for their own recreational trail system.

1. Introduction

1.1. Recreational conflict on multi-use trail systems

The global rise in nature-based recreation over the past two decades has increased the interest of researchers and managers to monitor visitor activity and interaction especially for multi-use trail systems (Fairfax, Dowling, & Neldner, 2014; Miller, Leung, & Kays, 2017). Information about trail use dynamics (e.g., extent and frequency of use) and the temporal and spatial overlap of visitors is essential for effective management of refuges and trail systems (Arnberger, Haider, & Brandenburg, 2005). A great amount of research on trail use activity has focused on the impacts on ecosystems (e.g., trampling of vegetation, erosion, disturbance to wildlife) (Marion et al., 2020; Salesa & Cerdà, 2020). Research on crowding (Arnberger & Brandenburg, 2007; Sever, Verbič, & Marušić, 2018) and carrying capacity (Sayan & Atik, 2011) is also abundant. However, reviews of trail-based activities have indicated that research on conflict between different recreational uses and groups is relatively scarce (Kling, Fredman, & Wall-Reinius, 2017). Conflict often arises from negative interactions or differences in goals or values between user groups. However, interactions between user groups are not always negative and may not result in conflict (Arnberger et al., 2005; Rossi, Pickering, & Bryne, 2013).

Research on conflict between different user groups is an increasingly

* Corresponding author. Dept. of Biology and Wildlife, University of Alaska Fairbanks, PO Box 757000, Fairbanks, AK, 99775-7000, USA.
E-mail addresses: smccahon2@alaska.edu (S. McCahon), tjbrinkman@alaska.edu (T. Brinkman), rklimstra@gmail.com (R. Klimstra).

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important area of investigation as participation in outdoor recreation expands. Accessible information on the extent and patterns of visitor activity may help users modify their behavior to minimize the potential for crowding and conflicts between different user groups. This response may help improve visitor experience and overall trail user satisfaction (Miller et al., 2017; Santos, Nogueira Mendes, & Vasco, 2016). Our goal was to develop an adaptable method for any recreational system that can generate spatially and temporally explicit estimates of trail use activity and encounter probabilities among different user groups. We used a wildlife refuge trail system in Alaska to demonstrate application of our method.

Researchers contend that conflict among trail users can arise when the goal or objective of one user group interferes with the presence or behavior of another user group (Jacob & Schreyer, 1980; Peterson, Birckhead, Leong, Peterson, & Peterson, 2010). Social conflict can occur when user groups do not share the same values or intentions regarding an activity (Donnelly & Vaske, 1995; Vaske, Needham, & Cline, 2007). For example, social conflict may arise between hunters and hikers that visit the same geographic areas because of differences in use (e.g., consumptive vs. non-consumptive) of local resources. Even without direct contact between users, the knowledge that one user group is recreating in the same geographic space as another with conflicting social values may diminish the quality of the experience for that individual (Carothers, Vaske, & Donnelly, 2001). Conflict can also occur at the interpersonal level (i.e., goal interference). Goal interference occurs when an individual s behavior alters the desired experience for another (Vaske et al., 2007). For example, backpackers with certain expectations of solitude may be displaced by off-highway vehicle (OHV) recreators (Switalski, 2018).

Interpersonal conflict is frequently reported on multi-use trail systems especially between cross-country skiers and snowmobilers (Vaske et al., 2007), between hikers and mountain bikers (Evju et al., 2021; Pickering & Rossi, 2016), and between motorized and non-motorized users (Rossi et al., 2013). Interpersonal conflict is the most prominent form of conflict when user groups share the need for a specific resource (e.g., snow) to participate in the activity (Vaske et al., 2007). Disruption of trails (e.g., trail damage), noise, and safety hazards (e.g., potential collisions) are common complaints expressed by recreationalists of different user groups. For example, one study found that hikers perceived the speed at which mountain bikers traveled to be a safety hazard (Cessford, 2003). Feedback from user surveys of another study showed that trail damage was the most common complaint from cross-country skiers who had a negative encounter with bikers (Neumann & Mason, 2019). Cross-country skiers rely on groomed trails to achieve their recreational goals, which were negatively impacted by fat bike tires causing trail rutting in warm conditions.

Conflict can also arise when different user groups use the same area at the same time (i.e., physical encounters) (Aikoh, Abe, Kohsaka, Iwata, & Shoji, 2012). Our present study investigated physical encounter conflict on a winter multi-use refuge in Fairbanks, Alaska. Encounters perceived as negative can lead to conflict and reduce visitors satisfaction (Dorwart, Moore, & Leung, 2009; Santos et al., 2016). Although encounters among different users on multi-use trails do not always generate conflict (Arnberger et al., 2005; Rossi et al., 2013), different users activities may require different management strategies (Neumann & Mason, 2019; Santos et al., 2016). A shortage of explicit (spatial & temporal) visitor use data often exists in many recreational areas which makes objectively addressing concerns or potential conflicts arising from visitor interactions difficult (Cessford & Muhar, 2003).

Collecting spatially and temporally explicit visitor use data in large recreational areas (e.g., parks and refuges) can be a challenging task given that many of the trail systems are remote, expansive, and have few access points. Several tested methods exist to obtain reliable visitor use pattern data depending on the characteristics of the recreational area (e.g., size, level of remoteness) and research question. These methods include field observations, camera recordings, traffic counters, interviews, and GPS tracking (Cessford & Muhar, 2003; Korpilo, Virtanen, Saukkonen, & Lehvavirta, 2018; Wolf, Brown, & Wohlfart, 2018). Each survey method has its advantages and disadvantages.

Field observations are useful for collecting highly detailed and contextual observations of visitor characteristics and behavior. However, this method requires a relatively high level of researcher time and effort. Therefore, field observation may not be useful for extended and continuous observation periods and data collection is often spatially and temporally limited. Also, the presence of the researcher has a greater likelihood of influencing behavior of the system and introducing bias. Camera recordings from trail cameras are a widely used monitoring method that can accurately quantify human trail-based activity (Buxton, Lendrum, Crooks, & Wittemyer, 2018; Conlon, 2014; Duke & Quinn, 2008; Miller et al., 2017). Trail cameras generate a high volume of long-term visitor use data non-invasively and can effectively identify hotspots of activity overlap (Miller et al., 2017). After camera installation, the time investment of a researcher is relatively low. However, it is time-intensive to process and evaluate recordings. Equipment is also costly and vulnerable to damage (Wolf et al., 2018).

Traffic counters (i.e., automated visitor counters) are one of the most used methods for collecting information on visitor use patterns. Their popular use is due to the high volume of data that can be collected with minimal effort and at low cost (Pettebone, Newman, & Lawson, 2010). However, most can only be used to record visitor numbers, time, and date, and are not able to distinguish between activity types on a multi-use trail system. Counters can also be triggered by non-target movements (e.g., animals, falling leaves).

Surveys are used to collect information about visitors attitudes, perceptions, and behavior and can be applied for conflict management. Datasets from surveys are not restricted to a spatial area or sampling period because interview participants can share perceptions of different times (e.g., past recollection of observations and experiences) and locations (Wolf et al., 2018). However, there are potential issues with recall and retrieving accurate locations of visitor use. Personal experience of interviewees may also shape perceptions and reduce objectivity. Surveys are most useful when complemented with other sampling methods, such as traffic counters, GPS tracking, or trail cameras (Wolf et al., 2018).

GPS tracking is another useful method that can be used to collect in-depth spatial and temporal data of visitor use patterns over an extended period. GPS tracking collects detailed information on visitor distributions over a large study area and allows for complex GIS analysis and visualization. However, because the datasets are detailed and expansive, analysis can be very time consuming and sample sizes are often limited (Wolf et al., 2018). This technique is considered more invasive to privacy and research subjects may behave differently when equipped with a monitoring device (Miyasaka, Oba, Akasaka, & Tsuchiya, 2018).

We selected trail cameras over the other survey methods in our study design because of their ability to collect season-long data passively and produce extensive observational information on visitor activity (Buxton et al., 2018; Conlon, 2014; Duke & Quinn, 2008; Miller et al., 2017). Our main objectives with trail cameras were 1) to estimate the extent and frequency of recreational trail activity by different user groups, and 2) to quantify the occupancy and encounter probabilities across space and time of different user groups. We estimated user group encounter probabilities to help identify locations that have the highest potential for congestion and conflict. Our novel method enhances current recreational monitoring methods by 1) differentiating user group activity across time and space, and 2) quantifying encounter probabilities. Our method is adaptable to any recreational area which provides another novel aspect to our design. We provide the option to vary the scale of temporal (e.g., hour, day, season) and spatial (e.g., trail segment, trail network) variable input to identify characteristics of trail use activity that are relevant to the various issues or circumstances that a specific recreational area may want to address. Researchers can adapt our method to any recreational trail system during any season. The season or other weather conditions should not affect the application of this method. With our method, these variables could be accounted for to further explain trail use dynamics. An important limitation to note is that our method focused on assessing physical encounter probabilities rather than the perceptions of users about the impacts on the trail system by others (Jackson & Wong, 1982). Other methods (e.g., trail user surveys) may be more appropriate to estimate user beliefs and attitudes. Our ultimate goal was to provide managers from any recreational area with a method that can estimate the amount of temporal and spatial overlap between user groups. Estimating activity overlap can better address current and future user interactions, minimize potential user conflicts, and optimize trail user satisfaction.

1.2. Case Study – Fairbanks Alaska

Our study was conducted in Creamer's Field Migratory Waterfowl Refuge (CFMWR) in Fairbanks, Alaska. CFMWR is a 9.4-km^2 wildlife refuge with a 43.5-km trail system that is open to the public year-round. Multiple trail uses (e.g., snowmobiling, skijoring, dog-mushing, biking, hiking, and cross-country skiing) are currently allowed within the CFMWR (Rosier, Kelleyhouse, & Rue, 1993). Concerns related to negative interactions and competing interests among public user groups have increased in recent years (R. Klimstra, Refuge Manager, personal communication, 12 October 2019). Concerns were related to safety, noise, and the disruption of groomed trails by different user groups. Interactions among user groups on the CFMWR trail system have been discussed; however, current information on trail use was insufficient to objectively address any potential conflicts arising from interactions. Therefore, we developed a monitoring method to quantify characteristics of recreational use on CFMWR during the winter season of 2019–2020.

2. Study area

2.1. Creamer's Field Migratory Waterfowl Refuge

Creamer's Field Migratory Waterfowl Refuge was established as a wildlife refuge in 1979. CFMWR serves as important waterfowl habitat, an urban green space, and recreational use area (ADFG, 2018). CFMWR is located within boreal forest and consists of wetlands, agricultural fields, and mixed forest (coniferous, deciduous) that attracts many species of waterfowl and migratory birds each year. Thousands of people visit this refuge each year to view wildlife, to utilize the trail system for outdoor activities, and to participate in educational opportunities and organized events such as dog mushing races and migratory bird festivals (Rosier et al., 1993).

The city of Fairbanks is in Interior Alaska and has a continental climate with cold winters and extreme temperature fluctuations (Shulski & Wendler, 2007). Typical winter temperatures can range between −23 °C and −12 °C (−10 °F to 10 °F) in early winter and between −17 °C and 7 °C (0 °F to 45 °F) in later winter; however, a wide range of winter temperatures occur, from -51 °C to 10 °C (−60 °F to 50 °F). Fairbanks receives an average of 1.7 m of snow per year that persists through winter months because of cold temperatures. These cold conditions provide reliable opportunities for skiing, dog-mushing, and other winter activities. The seasonal snowpack is typically established by October and lasts into April. Hours of daylight vary dramatically across the year from just under 4 h of daylight in midwinter to just under 22 h of daylight in midsummer (Shulski & Wendler, 2007). Therefore, winter recreational use is often limited by extreme cold and limited daylight hours on a trail system without artificial lighting.

3. Methods

3.1. Trail camera deployment and analysis

We deployed twenty-two Reconyx Hyperfire HC500 game trail cameras to monitor the winter recreational use of the trail system of CFMWR. We used a randomized grid (1-km cells) design to individually place cameras within each grid cell to cover the entire refuge. Our cameras captured approximately 90% of refuge trail segments (Fig. 1). Criteria for camera placement included one camera per trail segment and attempting to position the camera in approximately in the center of each grid cell.

We defined a trail segment as a continuous length of trail between connections with other trails. A new trail segment begins and ends where it contacts another trail or trail system entry point. Our study's capacity to capture off-trail use is limited but most of the winter activity is concentrated on the trail system where trails are regularly groomed. Deep snow and thick vegetation off the trail make off-trail recreational activity difficult and uncommon. Our design was implemented to help capture user trail activity associated with any entry point or route selected by the user. We were also able to differentiate user groups with trail cameras – a feature that cannot be done with trail counters. The durability, data memory capacity, and battery life of cameras also fostered high-resolution monitoring over a long winter season, which made trail cameras the optimal choice for monitoring visitor activity in our high-latitude environment.

We deployed cameras with infrared motion sensors on trail segments in late November 2019, coinciding with the beginning of winter trail use. We continuously monitored recreational activity during periods with snow cover until early April 2020 (n = 133 days) at which time snow melt hindered winter trail use. We did not measure summer use or periods without snow cover. Each camera was set up approximately 3 m above ground to reduce opportunities for camera theft. We pointed cameras down the trail to optimize the area of trail in each camera's field of view. We used camera rapid-fire settings to capture any detection of motion on a continuous basis. We checked instruments bi-monthly to ensure proper function and to download data.

We altered the image captured by trail cameras to protect individual identity. Plastic film with color bands was placed over the lens of each camera to sufficiently distort the image so that the viewer can only identify an individual's activity (Fig. A1). Our human research subject protocol was approved by the University of Alaska Fairbanks' Institutional Review Board (#1514594).

We installed twenty-two cameras but data from twenty-one were included in analysis due to one theft. We tagged trail camera images using Windows 10 File Explorer Application. User activity was labeled as one of the following types: hiking, biking, skiing, snowmobiling, dog-mushing, skijoring, or duplicate. Duplicates arose when consecutive images of the same subject occurred at the same location during a short time period (≤10 s). These were omitted from analysis to avoid double sampling. To simplify analysis, we categorized the six winter activity types into three groups: 1) snowmobile users (motor-powered), 2) dog mushers and skijorers (dog-powered), and 3) hikers, bikers, and skiers (human-powered). The number of occurrences of each activity type at each camera was recorded rather than the number of people due to our inability to distinguish between individuals within a group. Most occurrences were single users. Large groups (≥3) traveling together were rare. Date, time of day, and type of activity were recorded for each image and data were organized in Microsoft Excel. To quantify the temporal patterns of recreational winter trail use by different user groups, we calculated the total number of occurrences and proportion of activity across all user groups and study sites for each 15-minute interval, hour, day of the week, and month (see Appendix A). Tables and graphs were produced in R, Microsoft Excel, and ArcMap.

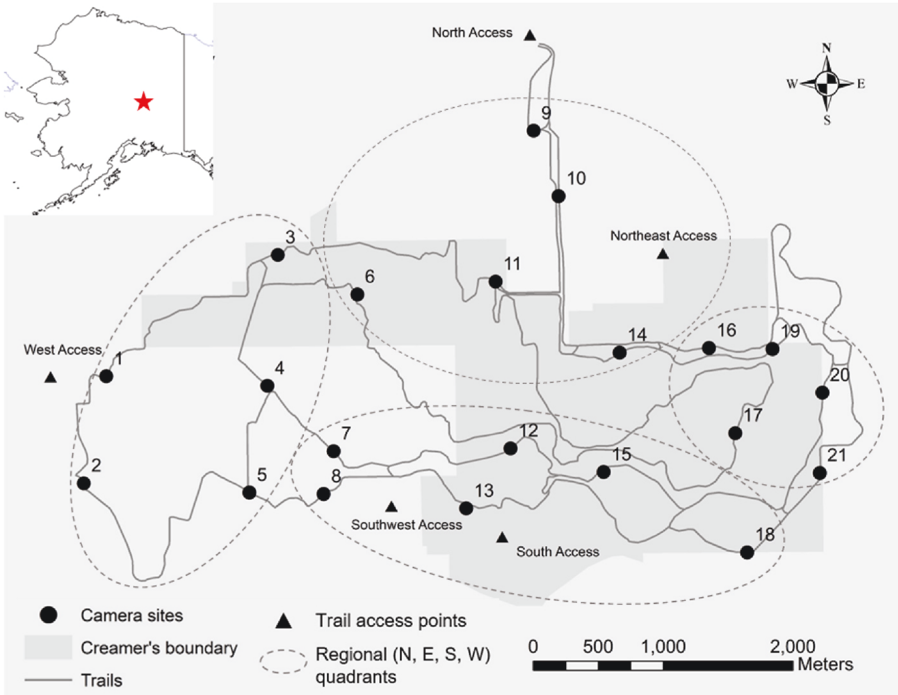

Fig. 1. Study design for game trail camera placement on the Creamer's Field Migratory Waterfowl Refuge winter trail system in Fairbanks, Alaska. Camera site locations (n = 21), major trail access points (n = 5), regional quadrants (n = 4), and the Creamer's Field Refuge boundary are labeled.

3.2. Occupancy and encounter probabilities

We estimated the probability of trail users from different groups encountering one another in space and time (i.e., overlap). We estimated encounters between users of different groups because potential for conflict is often greater between trail users of different groups compared to users within the same group (Santos et al., 2016; Wolf et al., 2018). To estimate the probability of encounter between groups, we needed to first calculate the probability of at least one user of a group occupying one trail segment/site within a given time interval (i.e., occupancy probability). For each user group, we calculated the number of unique days throughout the season where at least one trail user from a group was present on the trail system within each 15-minute interval between the hours of 11:00–18:00 (77% of daily trail activity occurred during these hours; $\bar{x}$ = 14:45 ± 3:15: Table 1). We then divided that number by the total number of days in the season that the site was monitored to determine the occupancy probability. We used these calculations for each user group and site across the trail system and scaled up both temporally and spatially. We estimated both hourly and daily occupancy probabilities for each user group. We estimated probabilities that spanned the entire refuge along with regional quadrants. We defined equal-sized quadrants by combining northern (sites 6, 9–11, 14), eastern (sites 16–17, 19–21), western (sites 1–5), and southern (sites 7–8, 12–13, 15, 18) sites together with the intersection located in approximately the center of the refuge (Fig. 1).

We chose 15 minutes as our smallest temporal unit of analysis. We assumed that if two different user groups were photographed at the same site within the same 15-minute interval that they were likely to encounter each other, at least visually. For application of our method to other recreational areas, researchers can use any time interval or time range that is reasonable for the characteristics of the trail systems in those areas.

We used individual occupancy probabilities to estimate the probability of two different user groups encountering each other on the same site/trail segment within the same 15-minute interval (i.e., encounter probability). User group occupancy probabilities were independent from activities of other groups; therefore, we used the multiplication probability rule for two events both occurring ($P(A \bigcap B)$) to estimate the encounter probability. The probabilities A and B represent the occupancy probabilities of two different user groups (Table 1). Additionally, we calculated the probability of one user group encountering any other user group by using the multiplication and addition rule $P(A) * (P(B \bigcup C))$. Each letter in this equation represents an occupancy probability of a different group (Table 1). We calculated the probability of the union of three or more events in R to scale up from 15-minute intervals to hourly and daily occupancy and encounter probabilities (Equation (1)). Each of the probabilities in the equation represent either an occupancy or encounter probability calculated from four continuous 15-minute intervals (hourly probability) or from all the 1-hour intervals monitored within a day between 11:00–18:00 (daily probability). We used the same method to estimate the probability of encounter across the entire refuge, between specific sites, and between refuge quadrants within a given time interval.

$$P(A \bigcup B \bigcup C \ldots) = P(A) + P(B) + P(C) - P(A \bigcap B) - P(A \bigcap C) - P(B \bigcap C) + P(A \bigcap B \bigcap C) + \ldots \quad \text{(Eq. 1)}$$

4. Results

4.1. Extent and frequency of trail use activity

The number of activity occurrences combining all sites and days captured by our twenty-one cameras (excluding duplicates and unusable images) was 27,523. User daily activity ranged from 1.5 users a day (205 total occurrences) at the lowest-use camera site to 26.1 users a day (3473 total occurrences) at the highest-use site. User daily activity had an average of 9.9 users (SD 6.1) per day (1310.6 total occurrences, SD 805.8) across all sites (see Appendix A, Fig. A2).

Temporal patterns (hourly to monthly) in activity were similar for all three user groups (Fig. 2, see Appendix A, Fig. A3-A). Monthly activity for human- and motor-powered users was highest in March. Monthly

Table 1
Occupancy and encounter probability formulas, definitions, and calculations.

Formula Component	Definition	Calculation
Occupancy Probability		
P (A)	Probability of a single user group (*A*) occupying one site/trail segment within a given time interval (i.e., 15-min) on any given day of the season	(Number of unique days where at least one member from a single user group was captured by a trail camera within a given time interval at one site)/(Total number of days that site was monitored over the season)
P (A B C)	***Scale up Across Space,*** Probability of one user group within a given time interval occupying site (*A*) OR site (*B*) OR site (*C*) ***Scale up Across Time,*** Probability of one user group occupying one site/trail segment within time interval (*A*) OR time interval (*B*) OR time interval (*C*)	P (A) P (B) P (C) P (A B) P (A C) P (B C) P (A B C)
Encounter Probability		
P (A B)	Probability of a single user group (*A*) AND another user group (*B*) encountering each other on one site/trail segment within a given time interval (i.e., 15-min)	*P (A) *P (B)*
P (A *B*)	Probability of a single user group (*A*) OR another user group (*B*) occupying one site/trail segment within a given time interval	*P (A) P (B)*
P (A *Other*)	Probability of a single user group (*A*) encountering any other user group (*Other: B* or *C*) on one site/trail segment within a given time interval	P *(A)* * *(*P *(B C))*
P (A B C)	***Scale up Across Space,*** Probability of two user groups within a given time interval encountering each other at site (*A*) OR site (*B*) OR site (*C*) ***Scale up Across Time,*** Probability of two or more user groups encountering each other at the same site or group of sites at time interval (*A*) or time interval (*B*) or time interval (*C*)	P (A) P (B) P (C) P (A B) P (A C) P (B C) P (A B C)

activity for dog-powered users was highest in December. Sundays and Saturdays typically had the highest activity for each user group. Mondays and Fridays typically had the lowest. Activity increased throughout the morning and decreased through the late afternoon and early evening. The highest level of activity occurred between the hours of 14:01 15:00 for each user group.

4.2. Occupancy and encounter probabilities

Daily site occupancy probabilities for motor-powered users ranged from 0.12 (i.e., probability of a single user group occupying one site/trail segment within any one 15-minute interval on any given day of the season) at the lowest-use site to 0.73 at the highest-use site for motor-powered users. The probability of a motor-powered user encountering a human-powered or a dog-powered user on the refuge on any given day was 0.96. The encounter probability was highest in the northern (0.71) and lowest in the eastern quadrant (0.34; sites 16 17, 19 21) (Fig. 3). Individual site 11 (0.43) in the northern quadrant had relatively higher daily encounter probabilities compared to other sites (Table A1).

Daily occupancy probabilities for dog-powered users ranged from 0.34 at the lowest-use site to 0.99 at the highest-use site (Fig. A6). The probability of a dog-powered user encountering a human-powered or a motor-powered user on the refuge on any given day was 0.99. The encounter probability was highest in the western quadrant (0.88) and lowest in the eastern quadrant (0.48) (Fig. 4). Sites 2 (0.52) in the western quadrant, 11 (0.42) in the northern quadrant, and 15 (0.46) in the southern region had relatively higher daily encounter probabilities compared to other sites.

Daily occupancy probabilities for human-powered users ranged from 0.28 at the lowest-use site to 0.99 at the highest-use site (Fig. A7). The probability of a human-powered user encountering a dog-powered or a motor-powered user on the entire refuge on any given day was 0.99. The encounter probability was highest in the western quadrant of the refuge (0.92) and lowest in the eastern quadrant (0.40) (Fig. 5). Sites 2 (0.58) in the western quadrant and 15 (0.51) in the southern quadrant had relatively higher daily encounter probabilities compared to other sites.

5. Discussion

5.1. Extent and frequency of trail use activity

Trail cameras are used to measure visitor activity on recreational trail systems (Arnberger & Eder, 2007; Campbell, 2006; Unger, Williams, Lawson, & Groves, 2020); however, data collected from them are often under-utilized. This is especially true when identifying hotspots of activity (Guo et al., 2019). Congestion hotspots (i.e., activity overlap) have been studied on busy trail systems with the use of camera-monitoring methods (Guo et al., 2019); however, few research exists that differentiates user group activity across time and space at congestion hotspots. Our study addresses this critical research gap. We demonstrate that activity and encounter rates of different user groups can be objectively quantified and scaled by applying a camera-based method and probability rule equations.

The most frequent activity types across space and time would be expected to have the most overlap (Santos et al., 2016). Most of the activity for user groups and encounters occurred at a minority of sites in our case study (Table A1 and Figs. 3 5). These high-use sites are around trail access points. Trail access points are hotspots that may experience more encounters because users that are recreating both short and long distances on the trail system utilize them. Cameras near these access points capture users that sometimes may depart and return on the same trail segment near the access point. Our results demonstrate that our method can help managers quickly prioritize where attention (i.e., sites with higher levels of congestion and encounters) needs to be allocated to reduce conflict. Identifying areas of congestion is also important for other areas of research including where environmental damage and trail erosion may be more likely to occur (Salesa & Cerda, 2020). Degraded trails can threaten the quality of visitor experiences by making travel uncomfortable or difficult or by diverting their attention away from nature (Dragovich & Bajpai, 2012; Leung & Marion, 1996). There may also be dissatisfaction among users expecting more solitude on congested trail systems. One study found that recreational users are willing to pay less to visit congested areas which may have economic impacts on more crowded trail systems (Gürlük, Atanur, & Turan, 2012).

Temporal patterns (hourly to monthly) were similar for all user groups. This indicates that peak activity times may be predictable and more prone to user interactions that may lead to conflict. Saturdays and Sundays during mid-afternoon (14:01 15:00) may be prone to higher activity overlap and conflict between different user groups. This period may have higher activity levels likely due to 1) visitors having time off work during the weekends, and 2) the mid-afternoon hours having warmer temperatures and adequate daylight for navigating the trails. Studies have shown that trail use increases when environmental conditions are ideal (Burchfield, Fitzhugh, & Bassett, 2012; Rutty & Andrey, 2014). One study found that 97% of recreationalists with weather-dependent winter activities (e.g., skiing, snowmobiling, and dog mushing) use weather forecasts when planning an activity outing

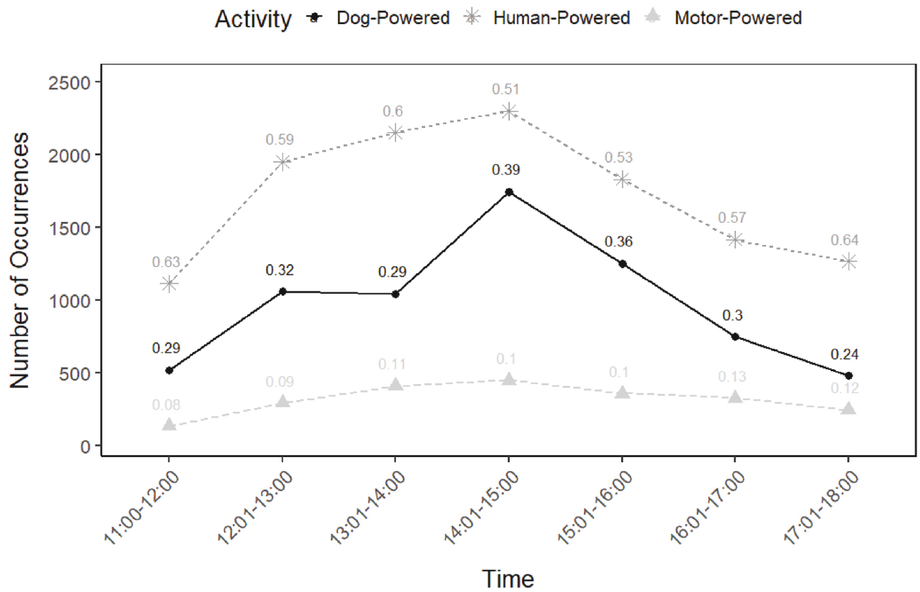

Fig. 2. Total number of occurrences of each activity type across time (24-h) for all camera sites. Numbers above points represent the proportion of activity occurrences for each user group during each hour throughout the season ($n = 133$ days).

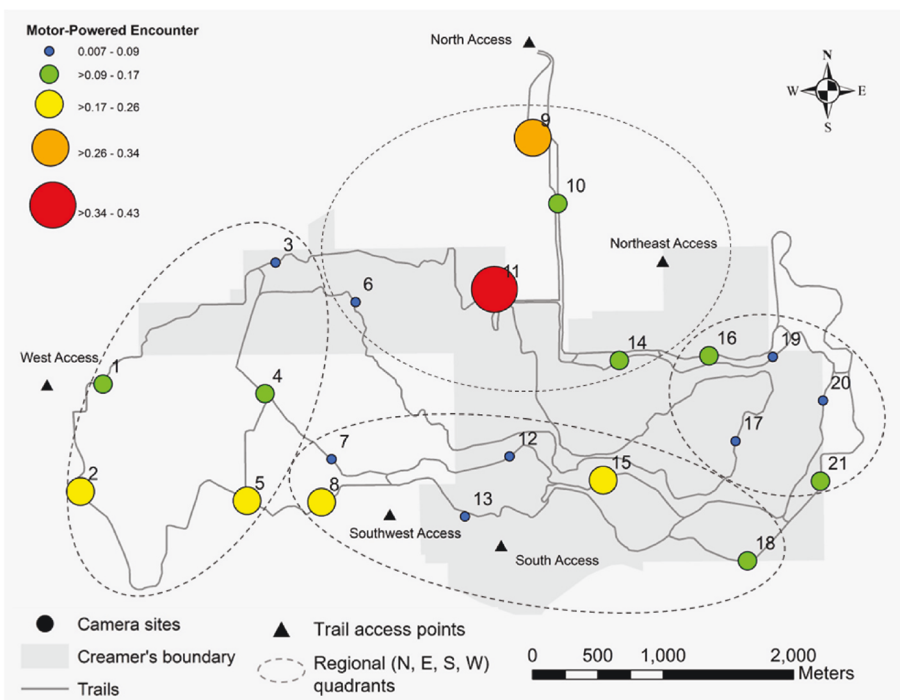

Fig. 3. This map displays the probability of motor-powered users encountering dog-powered OR human-powered users on any given day at each site (i.e., encounter probability). The size classes were calculated using an equal intervals approach.

(Rutty & Andrey, 2014). Winter recreationalists are attentive to extreme cold temperatures and poor snow conditions. Reduced participation during these conditions demonstrate the importance of weather information on leisure activities. Future studies could expand upon what we did with our methods and model the effects of various weather variables (i.e., snow conditions, temperature) or interactions with wildlife (Coltrane & Sinnott, 2015) into their own recreational system or study design.

5.2. *Occupancy and encounter probabilities*

We estimated two probabilities using multiplication and addition probability rules: 1) the probability of user groups occupying each trail segment (i.e., occupancy probability), and 2) the probability of encounter between different user groups (i.e., encounter probability) (Table 1). These probabilities allowed us to determine potential areas of conflict on the refuge (Figs. 3–5). We were also able to understand spatial dynamics of trail use activity more thoroughly by comparing these probability estimates to the number of occurrences of each activity type.

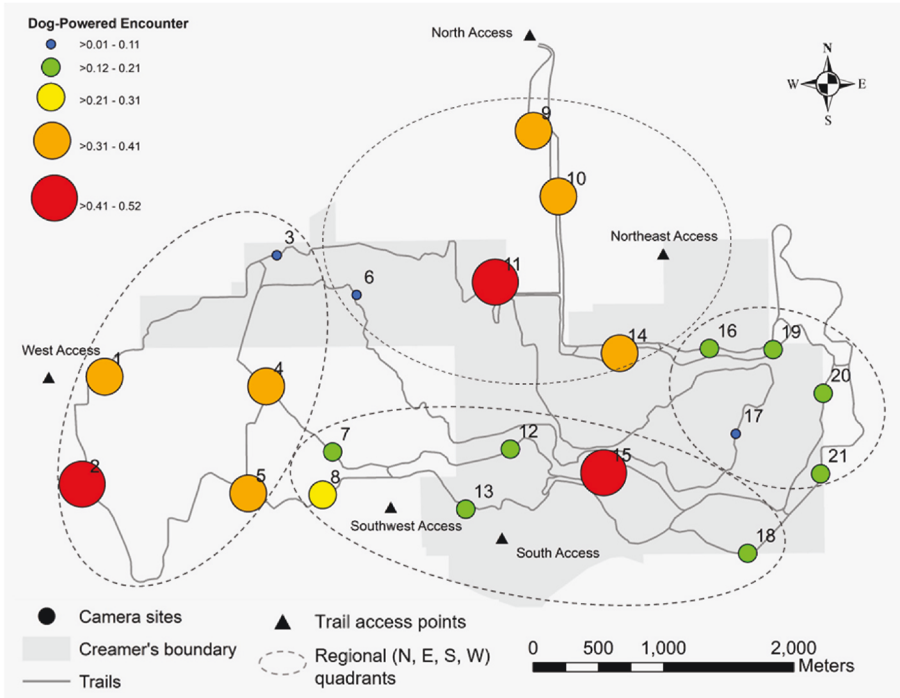

Fig. 4. This map displays the probability of dog-powered users encountering human-powered OR motor-powered users on any given day at each site (i.e., encounter probability). The size classes were calculated using an equal intervals approach.

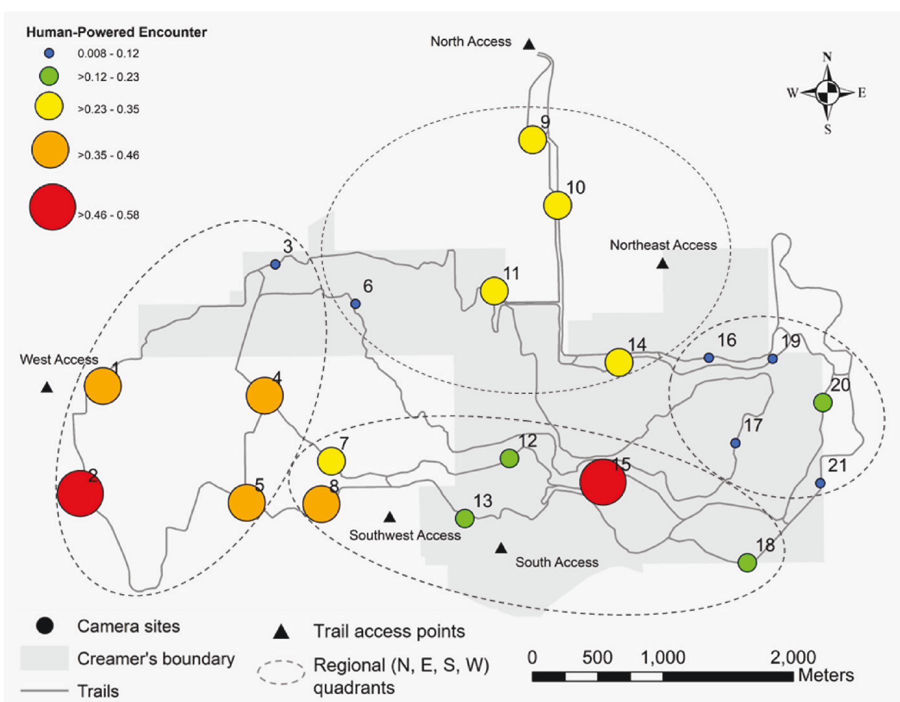

Fig. 5. This map displays the probability of human-powered users encountering dog-powered OR motor-powered users on any given day at each site (i.e., encounter probability). The size classes were calculated using an equal intervals approach.

Spatial mapping can help refuge managers better understand recreational demands and suitability of trails for certain uses especially in multi-use trail systems with competing spatial demands and limited acreage (Beeco, Hallo, & Brownlee, 2014). Spatial mapping can also be used to better understand how visitors enter and move through trail systems and parks, which can help predict future spatial movement of visitors and provide support for park design and management (Liu, Chen, Li, & Wu, 2021).

Maintaining the option to vary the spatial and temporal component in the probability formulas (Table 1) allows researchers to address various issues or circumstances relevant to their recreational systems. These issues include crowding and congestion (Arnberger &

Brandenburg, 2007; Sever et al., 2018), learning more about trail use dynamics (Kotut, Horning, & McCrickard, 2020), and better understanding human and wildlife encounters (Waldron, Welch, Holloway, & Mousseau, 2013). Many studies that focus on crowding are based on trail counters, surveys, and interviews (Arnberger & Brandenburg, 2007; Lindsey & Nguyen, 2004; Needham, Rollins, & Wodd, 2004). Our monitoring methods and the occupancy and encounter probabilities could advance these studies by providing a more quantitative and objective measure of determining where activity of different user groups is likely to be concentrated. Studies have shown that when encounters exceed a visitor s norm for seeing others, perceptions of crowding will increase (Vaske & Donnelly, 2008). Crowding is often a subjective judgement that there are too many people at the same time in the same area (Vaske & Shelby, 2008). Estimating occupancy and encounter probabilities can objectively quantify and better inform areas of congestion.

Understanding trail use dynamics is not only important for mitigating conflicts, but also for improving the sense of community on the trail and to increase trail user satisfaction (Kotut et al., 2020). Incorporating occupancy and encounter probabilities into studies on any recreational trail system will help improve the understanding of user group interactions. Information about user group interactions could provide an opportunity to integrate appropriate trail management strategies (Kotut et al., 2020). Some tested strategies include designating trails for different types of visitor use, informing visitors about congested areas, signage, meeting with user groups, and encouraging off-season use and use of less popular access points (Marion, Roggenbuck, & Manning, 1993). Another method would be to simply make the information available to user groups for them to use at their own discretion and potentially self-regulate use to ease congestion.

Our method can also be applied to better understand daily and seasonal movement of humans and wildlife to address concerns of human-wildlife encounters. Studies have used trail cameras to quantify human-wildlife conflict based on activity overlap (Coltrane & Sinnott, 2015). Our study can advance this by estimating the probability of encounter at a finer spatial or temporal scale. Our occupancy and encounter probability formulas can be applied to other monitoring methods, such as GPS tracking and field observations. Researchers can identify places of activity overlap and probability of encounter with user groups with our method as long as visitor type (or wildlife species), time, date, and location are recorded.

5.3. Study limitations and future research opportunities

There are a few limitations to this study that are important to note. First, we were not able to capture off-trail use due to our camera placement. Off-trail use does occur but is mostly limited to snowmobile use due to deep snow. Researchers could deploy cameras off-trail or incorporate public recreational use data (e.g., Strava) to better understand off-trail use. Secondly, we were not able to quantify how many people are on the refuge on any given day. Our study design only captured the number of occurrences of each activity type. We were not able to distinguish between individuals due to our privacy protection camera alterations. This limitation may be overcome by installing trail counters at access points which is a common practice in recreational areas (Pettebone et al., 2010). This information may provide insight on how trail activity (e.g., user dispersion) varies with visitation levels (D Antonio & Monz, 2016). Additionally, our study design and user privacy protection did not allow us to distinguish between single trail users and small groups traveling together which may be important for some research questions. Additional survey methods would be needed to obtain this information including GPS tracking, Public Participation Geographic Information System (PPGIS) mapping, or removal of the privacy protection alterations (Korpilo et al., 2018; Wolf et al., 2018). PPGIS mapping involves recruiting participants to provide geospatial information by identifying and marking locations on a map about perceived place attributes which could allow for individual distinction and more extensive sampling coverage. GPS tracking could provide greater in-depth spatial-temporal data including whole trail segments and duration of time in the recreation area (Wolf et al., 2018). However, both methods still have privacy issues and disadvantages of their own because they are voluntary methods that require public participation.

Another limitation is that our design does not incorporate duplicate data (i.e., consecutive images of the same subject at the same location during a short time period (10 s)). We omitted duplicates from our analysis to avoid double sampling. Duplicate data may be useful to identify locations where recreationalists spend more time or stop. Areas where visitors spend more time may have greater potential for encounters and conflict. Our occupancy probability analysis only detects for the presence of users. Our analysis does not provide insight into the duration of each site visit. Future studies could build upon our method and incorporate length of time spent or number of duplicates at each site with the use of cameras.

Our study design did not allow us to address if temporal and spatial overlap between user groups was perceived as negative. Additionally, we were not able to objectively address if attributes other than physical encounters (e.g., disruption of trails, garbage, and noise) are causing any negative experiences or conflict. Our study design does not incorporate attitudes and views from the public, so we are unsure if activity overlap attributes to conflict. Our study design could be complemented with survey methods (Troped, Whitcomb, Hutto, Reed, & Hooker, 2009) that incorporate user perception to identify areas along a trail segment that potential conflict and/or crowding may arise (Cessford, 2003; Pickering & Rossi, 2016). A future research opportunity would be to assess whether users that experience higher encounter rates have more negative perceptions of their overall experience. Previous research suggests that user demographics (e.g., age and employment status) and type of motivation moderate perceptions of crowding (Luque-Gil, Gomez-Moreno, & Pelaez-Fernandez, 2018). For example, nature visitors (i.e., those that were looking for contact with nature) perceived more crowding than learning visitors who were seeking cultural and biodiversity values. Interestingly, there were no differences between the number of encounters experienced. These differences indicate how complex perceptions of experiences can be (Luque-Gil et al., 2018).

6. Conclusion

We used trail cameras to develop an objective trail monitoring method that can generate spatially and temporally explicit estimates of trail use activity, occupancy, and encounter probabilities among different user groups. This tool can be adapted and applied to any recreational trail use system (e.g., park, preserve, forest, refuge) to help identify locations and times of high activity, congestion, or overlap between user groups that may have a higher potential for conflict. Maintaining the option to vary the scale of the temporal and spatial variable inputs allows managers to explore characteristics of trail use activity that are relevant to their recreational trail use system or specific research questions. Managers could utilize this information to 1) address current and future user concerns and interactions, 2) inform management plans, 3) monitor visitor information and management strategies, and 4) guide decision-making processes regarding trail use. These efforts could help minimize potential user conflicts and optimize trail user satisfaction.

Personal communication source

Klimstra, Ryan. (12 October 2019). *Refuge Manager, personal communication.* Creamer s Field Migratory Waterfowl Refuge.

CRediT authorship contribution statement

Shelby McCahon: Methodology, Investigation, Formal analysis, Writing – original draft, Visualization. **Todd Brinkman:** Conceptualization, Funding acquisition, Project administration, Resources, Methodology, Writing – review & editing, Supervision. **Ryan Klimstra:** Conceptualization, Investigation, Resources, Writing – review & editing.

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Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jort.2023.100614.

Appendix A

Fig. A1. We distorted trail camera images to protect the privacy of trail users. In this image, facial features are unidentifiable, but type of activity is clear

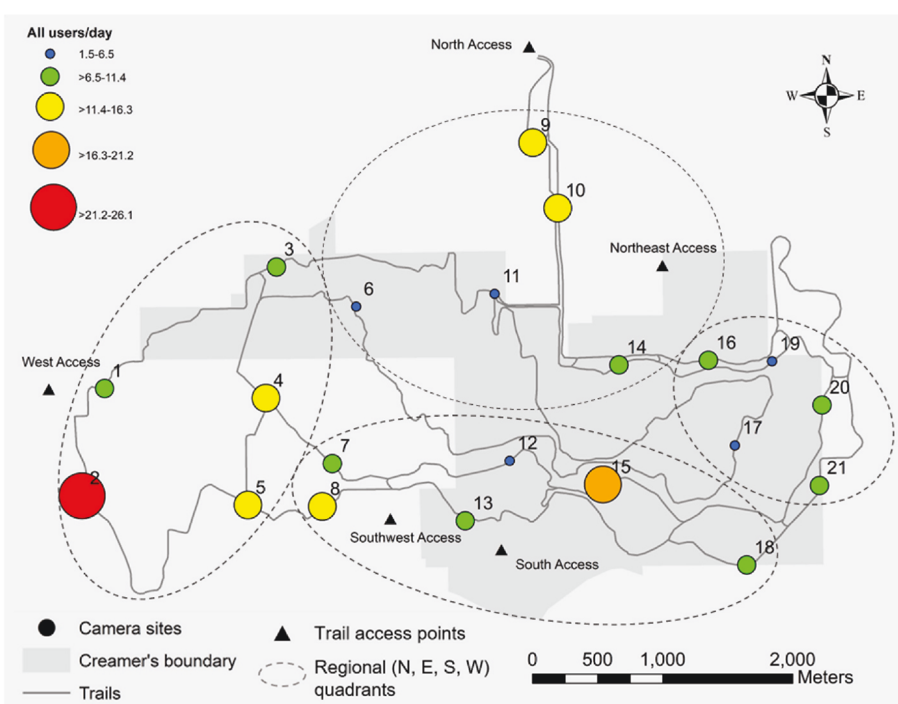

Fig. A2. This map displays the average number of occurrences per day at each site of all users combined. The size classes were calculated using an equal intervals approach

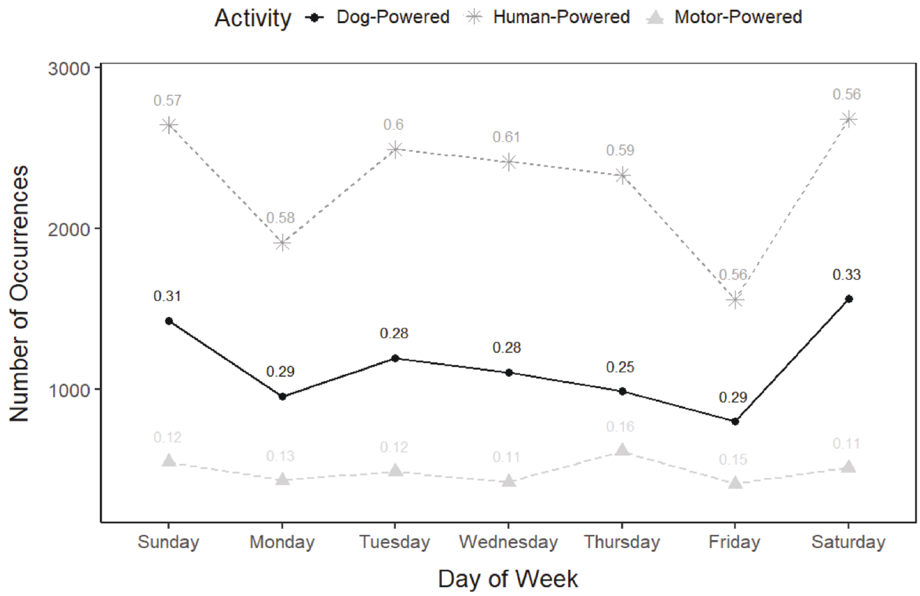

Fig. A3. Total number of occurrences of each activity type across days for all camera sites. Numbers above points represent the proportion of activity occurrences for each user group during each day throughout the season ($n = 133$ days).

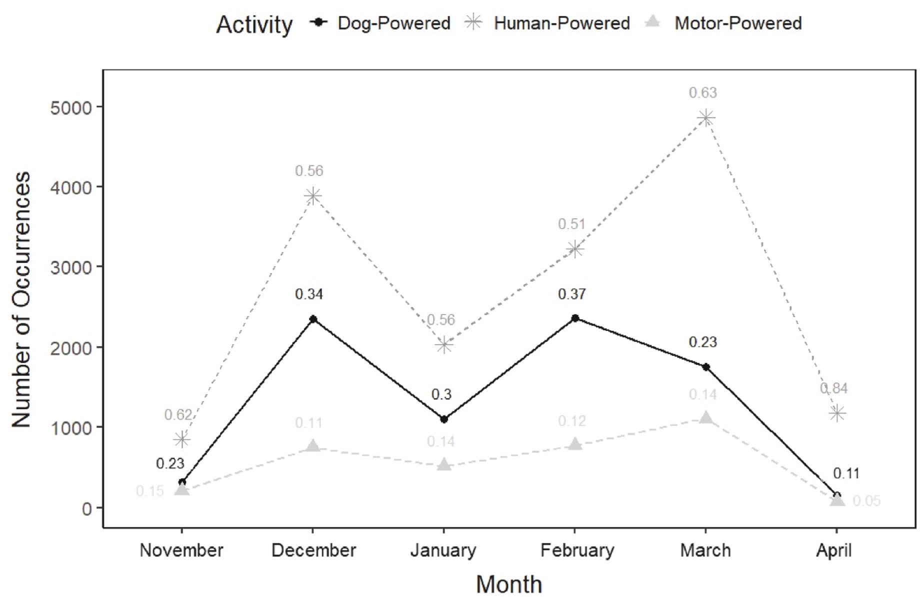

Fig. A4. Total number of occurrences of each activity type across months for all camera sites. Numbers above points represent the proportion of activity occurrences for each user group during each month throughout the season ($n = 133$ days). *Only 7 days were monitored in April, and only 4 days were monitored in November.

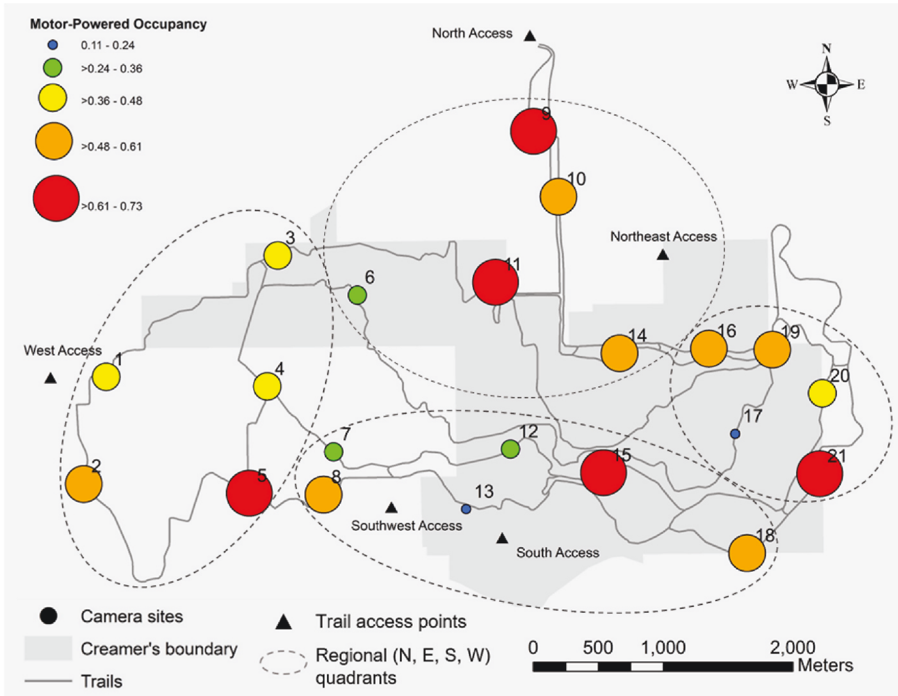

Fig. A5. This map displays the probability of at least one motor-powered user occupying each site on any given day (i.e., occupancy probability). The size classes were calculated using an equal intervals approach.

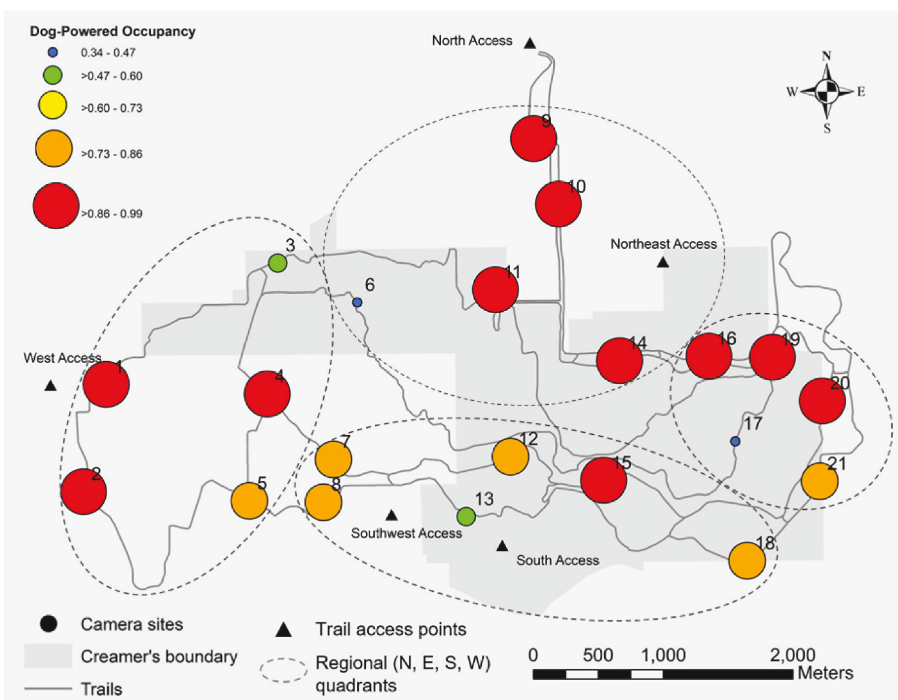

Fig. A6. This map displays the probability of at least one dog-powered user occupying each site on any given day (i.e., occupancy probability). The size classes were calculated using an equal intervals approach.

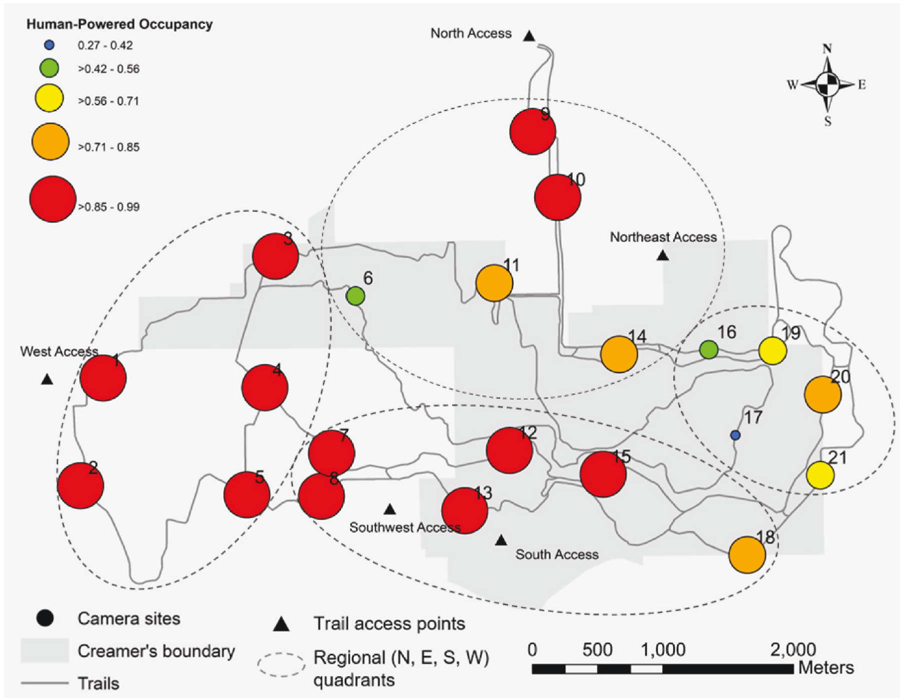

Fig. A7. This map displays the probability of at least one human-powered user occupying each site on any given day (i.e., occupancy probability). The size classes were calculated using an equal intervals approach.

Table A1
Encounter probabilities at each site for each user group. Bolded probability numbers represent sites with the highest probability for encounter for each user group.

Site Location	Motor-Powered	Dog-Powered	Human-Powered
1	0.12	0.37	0.40
2	**0.24**	**0.52**	**0.58**
3	0.06	0.08	0.11
4	0.15	0.33	0.37
5	0.22	0.36	0.43
6	0.01	0.01	0.02
7	0.07	0.20	0.25
8	0.19	0.32	**0.45**
9	**0.26**	0.39	0.31
10	0.16	0.34	0.31
11	**0.43**	**0.42**	0.32
12	0.07	0.13	0.17
13	0.02	0.12	0.14
14	0.18	0.33	0.24
15	**0.24**	**0.46**	**0.51**
16	0.12	0.17	0.10
17	0.01	0.01	0.01
18	0.10	0.15	0.15
19	0.09	0.13	0.10
20	0.07	0.15	0.18
21	0.11	0.13	0.10

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Shelby McCahon graduated from the University of Alaska Fairbanks in 2020. She participated in research involving avian ecology, toxicology, physiology, and recreational activity. She is currently a Master's student at the University of Idaho studying the effects of agriculture on migrating shorebirds. Her research interests include avian ecology, toxicology, and wildlife-habitat interactions.

Todd Brinkman is an Associate Professor with the Institute of Arctic Biology & the Department of Biology and Wildlife at the University of Alaska Fairbanks. His research interests include human-environment interactions, human dimensions of wildlife management, and large-mammal ecology.

Ryan Klimstra worked with Alaska Department of Fish and Game from 2015 until 2022 as wildlife biologist studying and managing many big game species and predators. He also worked on hunter access issues and user conflict surrounding a multi-use trail system in the heart of Fairbanks. He recently moved to Missoula, Montana and is now working with Fish, Wildlife and Parks as area biologist focusing on elk, two deer species, predators, and urban wildlife interactions.