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A Snapshot into the Lives of Elephants: Camera Traps and Conservation in Etosha National Park, Namibia

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Abstract: Knowledge of elephant movement and grouping patterns in the wild is critical for their management and conservation. Much of these data come from GPS collar data and aerial surveys, which have provided invaluable information, but data from these methods are often limited to small groups or entire populations. Effective elephant management requires both generalized and localized methodologies. Here, we propose the expanded use of camera traps in research relating to elephant localized movements and grouping patterns as an additional tool for elephant conservation management. In this study, we use a battery-powered camera trap to provide daily high-resolution data of African savanna elephant (*Loxodonta africana*) grouping patterns over the course of an entire year. We present findings on the seasonal and diurnal grouping patterns of elephants at a waterhole in the northeast corner of Etosha National Park from July 2016 to June 2017. The frequency of elephant occurrences varied seasonally and diurnally across all group types (solitary male, male, family, and mixed groups), while group sizes did not vary seasonally, except for male groups. Solitary males occurred relatively equally throughout the day, while male and mixed groups occurred the most midday, and family groups occurred the most in the afternoon. Additionally, we measured the reliability of research assistants when collecting group type and group size data from the camera trap images. Intra- and inter-observer reliability was excellent among and across research assistants, highlighting the potential for non-specialist observers to have greater involvement in camera trap data collection. Our results support the use of camera trap data where GPS collars and aerial surveys are not feasible and where higher-resolution data are needed for more localized management. Finally, we discuss our experience with two different types of camera traps to highlight the pros and cons of each approach.

Keywords: elephant; conservation; camera trap; grouping patterns; seasonality; diurnal; observer reliability; human–elephant coexistence

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1. Introduction

Elephant movement and grouping patterns vary widely across Africa. They depend on region, protected area status, rainfall, habitat fragmentation, season, perceived risk, sex, and dominance status [1–12]. Much of this research has largely relied on GPS tracking collars and aerial surveys. GPS collars provide valuable fine-scale assessments of elephant movement but often limit information to a small number of individuals. In contrast, aerial surveys provide large-scale assessments, but data are generalized to entire populations at a single point in time. Both methods also require coordination between multiple stakeholders, are expensive and time-consuming, and in the case of GPS collars specifically, may be invasive or even dangerous to employ for humans and elephants alike. Moreover, elephants also display inter-individual variability in movement patterns and foraging strategies [6,10,11,13], but current methods of tracking elephants over the long term do not often consider this inter-individual variation. As is evident by the expansive toolbox of human–elephant conflict mitigation strategies [14], effective elephant management requires a combination of generalized and localized approaches [15]. Thus, while the knowledge we have gained from the current methodology is substantial, the expanded use of alternative, more accessible monitoring tools can uncover new aspects of elephant grouping and movement behavior.

Camera trap data can be used as an alternative to previous methods to assess elephant movement and behavior. Camera traps are used widely in conservation work as a less expensive and less time-consuming way to assess animal populations and obtain critical data about wildlife movements, dynamics, and their habitats (reviewed in [16]). Camera traps have been used in elephant research and management to monitor both captive and wild elephants but have been rarely used to monitor elephant grouping patterns throughout the year. In captivity, camera traps are largely used to monitor welfare. In zoos, for example, elephant activity budgets, habitat use, and social interactions are researched [17]. One study in Zambia focused on elephants used for tourist encounters to track overnight behavioral interactions between individuals and monitor recumbent sleep patterns across tethering conditions [18]. In wild elephant research, camera traps were used to collect population data on the elusive African forest elephant [19], to investigate savanna elephant responses to low and high anthropogenic risk areas [9], monitor savanna elephant crop-raiding deterrent methods [20], and understand habitat use of Asian elephants [21]. Camera traps can also serve as an early warning system to alert communities of elephants' impending arrival so people can prepare to prevent elephants from entering sensitive land [22]. Finally, camera trap photos are used to compile and regularly update individual ID profiles and explore leadership in male elephants [23]. Previous uses of camera traps in elephant research provide a valuable framework to expand upon.

Despite the many advantages, data collection from camera trap photos or videos is time-consuming, currently limiting wide-scale use in management practices. However, recent innovations have opened the door to automated methodologies [24]. Namely, the use of artificial neural networks aids in the automatic detection of elephants in photos [25], reducing the number of human hours needed to review the photos. However, the technology is not yet widespread, and many researchers and park managers do not have access to this technology. Instead, the time-consuming task of camera trap data sorting, collection, and analysis can be achieved with the aid of undergraduate research assistants. Previous research using undergraduate students (non-specialist observers) to collect data on elephant behavior using video camera traps was successful, where students demonstrated high observer reliability [26]. Considering the success with the more difficult task of interpreting and coding behavior, non-specialist observers might also be successful in reliably collecting non-video camera trap data.

Our research uses camera trap methodology to study elephants in Etosha National Park (ENP) in Namibia, expanding our knowledge of ENP's elephant grouping patterns year-round. In ENP, much of the previous work on elephant movement and grouping patterns was conducted with GPS collars [2,5,10,27–29], aerial surveys [4,30], and satellite telemetry [4]. Despite all that is known about ENP's elephant movement patterns, ENP covers a large area with a population of over 2900 elephants [30]. Camera trap use in ENP offers a low-cost and possibly low-effort alternative to collaring or aerial surveys to track elephant grouping patterns over time. Given the large variation in how elephants use the landscape in ENP, a deeper and more site-specific understanding of elephant grouping patterns at different waterholes in the park can be used to inform management decisions with regard to water needs and habitat use. Here, we present elephant grouping patterns assessed using camera trap data collected at Mushara waterhole across one year, from July 2016 to June 2017. The first aim was to assess diurnal group dynamics including, (1) the seasonal occurrence of and average group size of elephant groups in the wet and dry seasons, and (2) the occurrences of group types throughout the day. The second aim was to assess the reliability of data collection by research assistants. This research contributes to our expanding knowledge of elephant movement and supports the expanded use of camera traps in elephant conservation and research.

2. Materials and Methods

2.1. Study Site

Data were collected at Mushara waterhole (hereafter referred to as Mushara) located in the northeastern region of Etosha National Park (ENP) in north-central Namibia. Though ENP is fully fenced, fencing quality varies, and breaks caused by elephants are frequent, particularly during crop harvest and tree fruiting season from April to May. Mushara is an artesian spring, the flow controlled by a ball valve and channeled into a cement trough that spills into a natural clay pan. Mushara is the only year-round source of water within a 10 km radius [31]. Mushara is one of three remote waterholes in the region and is closed to tourists. Mushara is the site of a yearly, long-term elephant monitoring project, where individual identities of males and females have been tracked and updated over the years, during the June–July field season. Thus, Mushara is an ideal field site to collect fine-resolution behavioral and ecological data (for example, [31–34]) and broader grouping patterns, such as the data presented herein.

2.2. Camera Trap Photo Collection

High-resolution photos were taken by a battery-powered, Moultrie digital camera trap (Moultrie Feeders, Calera, AL, USA) from July 2016 through June 2017. Photos were taken every 15 min, during daylight hours from 7:00 a.m. to 5:45 p.m. This window of time allows for consistency in the sampling period since sunset occurs at different times throughout the year. The camera trap was fixed at the top of the 8 m tall research tower, situated 80 m from the water hole (Figure 1). The camera trap faced the south, capturing most of the waterhole. The camera trap was situated on the tower to capture the eastern edge of the pan and the water trough. This part of the waterhole is considered the most important area, as the freshest water flows from the head of the trough (far left of the trough). As such, upon arrival, elephants tend to gather around the trough and into the eastern edge of the pan, creating an optimal space to count the elephants. Elephants tend to spread out along the rest of the trough and into the eastern edge of the pan.

Figure 1. View from above the Mushara waterhole, depicting the tower and waterhole, where the source of a natural spring flows up into a trough and runs out into a natural clay depression, or pan. The camera is aimed at the head of the trough, where the highest density of elephants is likely to be at any one time (where two of the three elephants are standing in the image). The field of view is wide enough to capture most elephants that might be drinking from the pan as well.

2.3. Data Collection from Photos

Initially, about 8300 photos were collected across the entire year and were previously sorted by Utopia Scientific volunteers into two categories, elephants present and no elephants present. Data collection on the 4492 photos containing elephants was conducted using Adobe Lightroom Classic (Adobe, 2023) by five undergraduate research assistants (observers A, B, C, D, E). Research assistants were trained by J.L.B. and C.E.O.-R. on elephant group determination and counts. Due to time constraints, about half the photos were analyzed by observers A and B (n = 2328). The students split the photos up by odd- and even-numbered days of each month. The second half of the photos were analyzed by observers C, D, and E (n = 2064). Each month's photos were split into three groups by date (1st–10th, 11th–20th, 21st–30th/31st), and each student was assigned a different group of photos every month. Photos used for observer reliability (n = 100) and those with data collection errors (n = 26) were removed from further analysis, leaving a total of 4366 photos.

For this research, we were interested in the dynamic, long-term, grouping patterns of elephants that visit Mushara. From field research, we know that individuals (males and family groups) regularly return to Mushara during the height of the dry season, some as frequently as daily, others a couple times a week, and some only a few times. In addition, some groups, the males especially, will stay at the waterhole for over an hour, during which individuals will come and go from the waterhole. Since the data collectors were not trained to identify individuals across sequential photos and we were only interested in assessing broad-scale grouping patterns, we kept all photos and assumed all elephants in each photo were an independent "group". As such, each photo only contained one group type.

For each photo, data were collected on elephant group type, group size, and the presence of other animals. Group type was defined by four categories: solitary males, male groups (no females present), family groups (females and offspring with no adult males present), and mixed groups (adult males and family groups). Any elephants that were visible in the photos were counted, including those at the edge of the clearing. We also collected environmental (moon phase, temperature, and barometric pressure) data from the bottom of the photos along with the date and time (Figure 2). To evaluate diurnal grouping patterns, we considered three categories for the time of day: morning, from 7:00 a.m. to 11:45 a.m.; midday, from 12:00 p.m. to 3:30 p.m.; and afternoon, from 3:45 p.m. to 5:45 p.m. For photos taken outside of the 15 min interval (due to camera trap error) and those that were in between categories, we grouped the photos into the numerically closest time category. ENP has three main seasons (cold-dry from May to August, hot-dry from September to December, and hot-wet from January to April) [10]. However, for this study, we considered only two seasons that correlate with rainfall: wet (November–April; Figure 2A) and dry (May–October; Figure 2B).

2.4. Statistical Analysis

We tested where there was an association between (1) season and group occurrences, and (2) diurnal period and group occurrences. A Pearson's chi-square (χ^2) contingency test was performed for both assessments using the 'chisq.test' function in the R package *stats* [35]. To assess differences in seasonal group sizes, we used a non-parametric Wilcoxon rank sum test (WRST). Three WRSTs were performed, one for each group type. Models were performed using the 'wilcox.test' function in the R package *stats* [35] with the alternative parameter set to "two.sided". Assumptions were assessed and met for all models (see R code for details).

To assess the reliability of observers, intra-rater reliability and inter-rater reliability were calculated for group type and group size using a subset of 100 photos. Eight photos per month were randomly selected, with an additional four photos randomly selected from four different months.

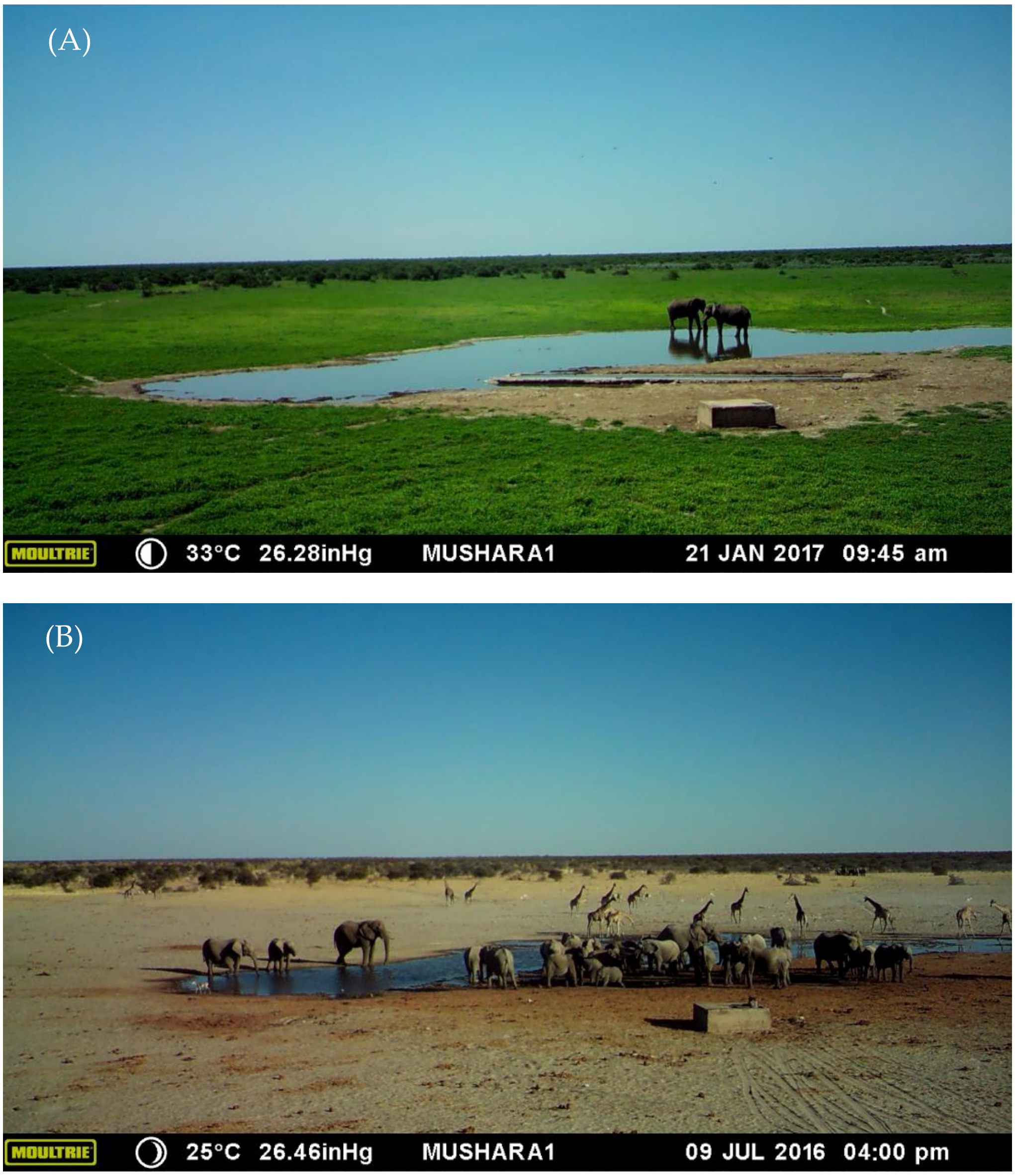

Figure 2. Two examples of camera trap photos and the data collected from the bottom strip, in order from left to right: moon phase, temperature, barometric pressure, the name of the camera, the date (day, month, year), and time. (**A**) Wet season, male group. (**B**) Dry season, mixed group: two adult males are present, one is the third from the leftmost side of the waterhole and the other in the middle of the far side of the trough, towering above the adult females, while the family group makes up the rest of the elephants.

Data collected by observers C, D, and E were used to calculate intra-rater reliability due to time constraints on observers A and B's internships. Intra-rater reliability for group type was calculated using Cohen's kappa, which is suitable for categorical data [36]. We followed the modified, more stringent interpretation of kappa where any values below 0.60 are inadequate, values 0.60 to 0.79 are moderate, 0.80 to 0.90 are strong, and 0.91 to 1.00 are almost perfect [36]. The 'kappa2' function in the *irr* R package [37] was used, with the weight specification set to "unweighted" for the nominal group type categories. Intra-rater reliability of group size was calculated using the intraclass correlation coefficient (ICC) with the 'icc' function in the *irr* R package [37], using a two-way mixed effects model with an absolute agreement type. We followed conventional interpretation standards where values closer to one represent higher agreement and values closer to zero represent lower agreement [38].

Inter-rater reliability was calculated for group type using Fleiss' kappa, a modified version of Cohen's kappa, suitable for more than two raters [39]. Fleiss' kappa is interpreted the same way as Cohen's kappa [40], so we used the modified interpretation [36]. The function 'kappam.fleiss' in the *irr* R package [37] was used. Inter-rater reliability for group size was calculated with the ICC using the same R functions and interpretation as the intra-rater reliability of group size. All five observers were included in the inter-rater reliability analysis. Since observers A and B collected one round of observer reliability data, only the first round of reliability data was used for observers C, D, and E for more direct comparisons between all five observers.

Data summaries, visualization, and analysis were performed using R programming software (version 4.3.1) [35] and RStudio (version 2023.06.1) [41]. All statistical analyses were assessed at $\alpha = 0.05$.

3. Results

The frequency of elephant occurrences at Mushara varied seasonally and diurnally across all group types, while overall, group sizes varied diurnally but not seasonally. Intra- and inter-rater agreements were excellent. For the 4366 photos analyzed in the study, the wet season had 1396 photos and the dry season had 2970 photos (Table 1). Each month had an average of 396.9 ± 247.4 (median = 336, range = 18, 782) photos, and each time of day had an average of 1455.3 ± 729.3 (median = 1078, range = 992, 2296) photos (Table 1). Of the analyzed photos, 28.6% were solitary males, 48.9% were male groups, 5.9% were family groups, and 21.0% were mixed groups. See Table A1 for sample sizes of each group type per season and time of day. The rest of the results section is ordered as follows: seasonal variation in group type occurrence and group size, diurnal group occurrences, and observer reliability statistics.

Table 1. Total number of photos (n) with at least one elephant present, per each season, month, and time of day. All 7 March photos were used for observer reliability analysis.

Season	Month	Time of Day			Total Photos per Month (n = 4366)
		Morning (n = 1078)	Midday (n = 2296)	Afternoon (n = 992)	
Wet (n = 1396)	January	107	101	36	244
	February	4	8	6	18
	March	0	0	0	0
	April	10	26	31	67
	November	180	236	83	499
	December	213	268	87	568
Dry (n = 2970)	May	34	154	97	285
	June	35	148	153	336
	July	23	146	122	291
	August	63	364	162	589
	September	161	417	109	687
	October	248	428	106	782

3.1. Seasonal Variation in Group Occurrence and Size

A significant relationship was found between group type and seasonal occurrence ($\chi^2 = 194.33$, df = 3, $p < 0.001$). Overall, all group types were most frequent during the dry season (Figure 3). Mixed groups were observed during the dry season 84% of the time, followed by 77% and 67% for family and male, and 56% for solitary males.

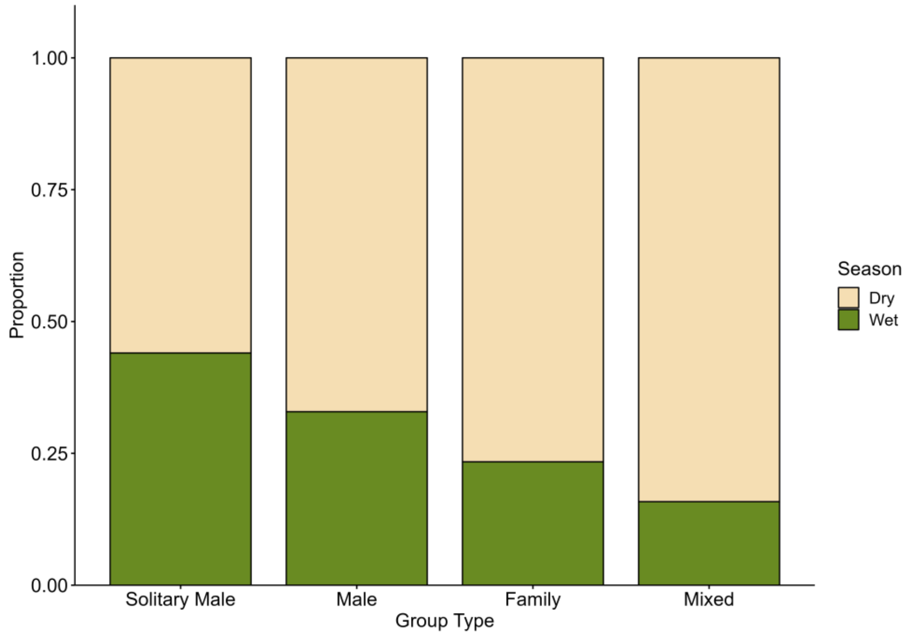

Figure 3. The occurrence of each group type between the dry and wet seasons. Proportions are displayed as within-group occurrences for each season. A significant relationship was found between group type and seasonal occurrence (χ^2 = 194.33), df = 3, p < 0.001). Sample sizes vary between group types: solitary males, n = 1197; male groups, n = 2043; family groups, n = 248; mixed groups, n = 878 (Table A1). All four group types occurred at the Mushara waterhole most frequently during the dry season.

Family (Wilcoxon rank sum test, p = 0.998) and mixed (Wilcoxon rank sum test, p = 0.162) group size did not appear to vary considerably between seasons (Figure 4). Male group sizes were significantly different between seasons (Wilcoxon rank sum test, p < 0.001), though the differences were small (wet season average: 3.9 ± 2.3, dry season average: 4.5 ± 2.9). On average, all groups were larger in the dry season, however, the differences were small (Figure 4). Male groups were the smallest groups observed with an average of under five individuals across both seasons; family groups comprised about fourteen individuals across seasons; mixed groups were the largest on average with about twenty-five individuals across seasons. The minimum and maximum values within each group type were similar across seasons, but the dry season had more large-outlier groups than the wet season.

3.2. Diurnal Variation in Group Occurrence

A significant relationship was found between group type and time of day (χ^2 = 373.9, df = 6, p < 0.001). Solitary males occurred in fairly equal proportions throughout each time period (Figure 5). On the other hand, male and mixed groups were seen the most frequently at midday, making up about 60% of their respective occurrences, while about 60% of family group visits were in the afternoon (Figure 5). None of the groups were observed in large proportions in the morning compared to other times of day, but about 33% of solitary male and 26% of male occurrences were in the morning, compared to about 15% for mixed groups and 8% for family groups.

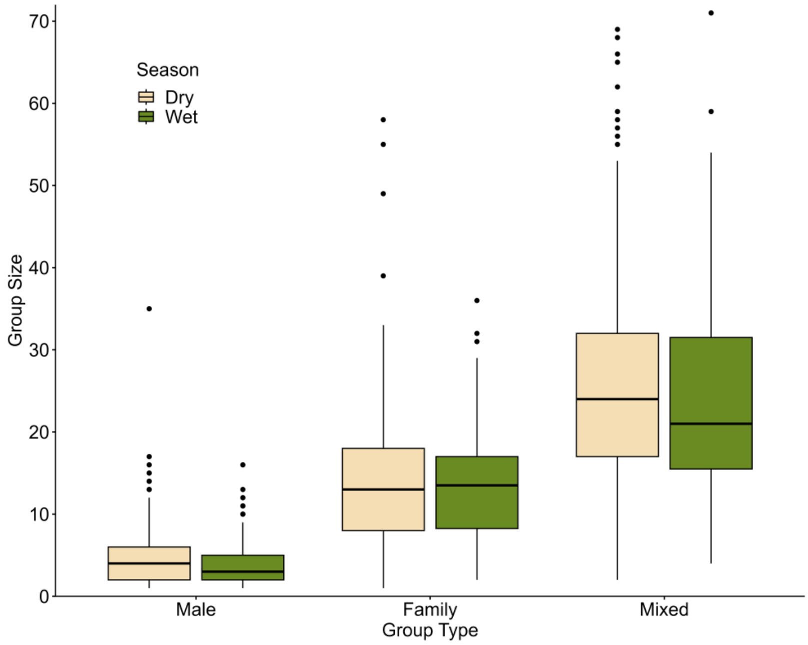

Figure 4. Group sizes of each group type in the dry and wet seasons. The solitary male group is not displayed here as the group has only one individual. Sample sizes for each group type are the same as in Figure 3 and a more detailed description of group sizes is presented in Table A1. Thick horizontal bars represent the median, the vertical length of the box represents the interquartile range, vertical lines represent the minimum and maximum values, and filled circles represent outliers. Family (Wilcoxon rank sum test, $p = 0.998$) and mixed (Wilcoxon rank sum test, $p = 0.162$) group size did not appear to vary considerably between seasons, while male group sizes were significantly different (Wilcoxon rank sum test, $p < 0.001$). However, each group type was larger and had a larger variation in group size during the dry season, evident by the outliers and large minimum and maximum values.

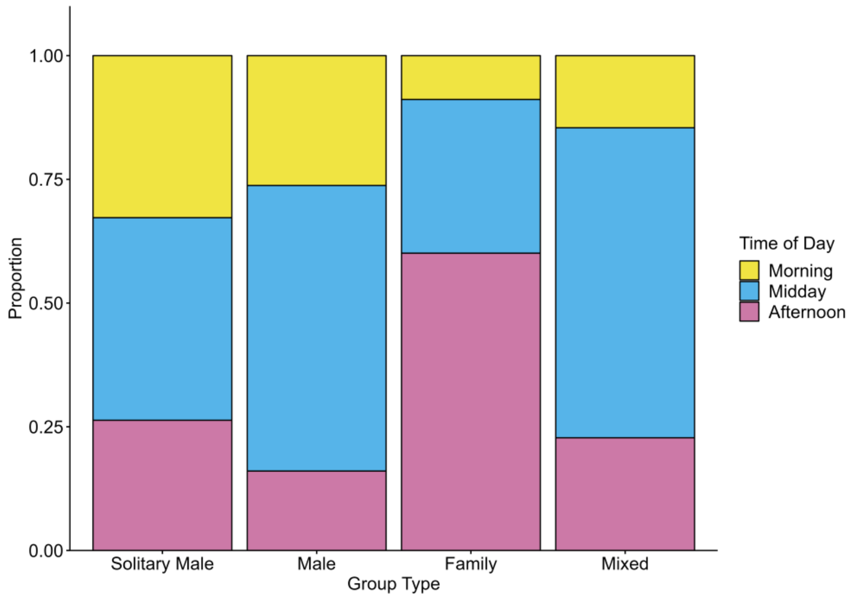

Figure 5. The diurnal occurrence of each group type. Proportions are expressed as within-group occurrences. Sample sizes for group type are the same as in Figure 3, while more detailed descriptions of sample sizes are presented in Table A1. A significant relationship was found between group type and time of day ($\chi^2 = 373.9$, df = 6, $p < 0.001$). Solitary males occurred in fairly equal proportions throughout the day, while male and mixed groups occurred most frequently at midday, and family groups most frequently in the afternoon.

3.3. Observer Reliability

Across the three raters, intra-rater agreement was strong for group type (Cohen's κ = 0.894) and excellent for group size (ICC = 0.995). Across the five raters, inter-rater agreement was strong for group type (Fleiss' κ = 0.897) and excellent group size (ICC = 0.997).

4. Discussion

This study demonstrates the potential of camera trap methodology as a complement to existing methods used to assess elephant grouping and movement patterns. All elephant group types showed much greater prevalence at the waterhole in the dry season compared to the wet season (Figure 3). However, group sizes strongly varied between group types. Within each group type, little variation in group size was observed between seasons, with the exception of some very large group sizes observed in the dry season (Figure 4). Diurnal occurrences significantly varied among group types, with nearly equal proportions of solitary males throughout the day, higher numbers of male and mixed groups at midday, and higher numbers of family groups during the afternoon (Figure 5). For this research, we assessed grouping patterns in broad contexts, possibly obscuring more fine-scale details. Regardless, camera trap methodology provides a greater potential for exploring elephant grouping patterns in even greater detail, especially when expanded to include additional years of data or locations of camera trap placements. Overall, we show that our grouping patterns results align with previous research in ENP [2,5,10,27–29] and similar climatic regions [42–44]. Additionally, our excellent observer reliability results further support the potential of continuing to include non-specialist observers, such as undergraduate research assistants, in conservation efforts.

4.1. Seasonal Grouping Patterns

At Mushara, we found a significant association between group type and season, where all group types occurred more frequently during the dry season (Figure 3). On average, all group types were larger during the dry season (Figure 4), though the differences in group size were not significant. Elephants in ENP have a preference for grass-dominated landscapes, and females especially prefer to stay near ephemeral sources of water and preferred vegetation, such as grasses, during the wet season [10], similar to elephants in comparable environmental conditions [42–44]. Family groups are dependent on high-quality vegetation to support lactating cows and the reduced mobility and higher needs of calves [44].

Male, family, and mixed groups were larger and occurred in proportionally higher numbers during the dry season than the wet season (Figures 3 and 4), contrasting findings in Amboseli [45]. Elephants appear to be heavily relying on other water sources during the wet season, likely staying near ephemeral water and preferred vegetation [10], and only seeking out permanent water sources, such as Mushara, during the dry season [2,5,10,29]. Further, while Etosha's elephant home-range sizes are larger during higher rainfall conditions [2,5], Mushara might still be out of range of preferred resources for many family groups. If so, the families that do visit Mushara during the wet season might be lower ranking and must extend their home ranges into areas with less-preferred resources, similar to the subordinate family groups in northern Kenya [12].

The relatively small differences in group occurrence and size between seasons might be due in part to the pooling of six months of data for each season. Assessing groups in two broad categories, such as wet and dry seasons, does not provide information on how grouping patterns change throughout each season. Additionally, Etosha rainfall varies across years, where some years have high amounts of rainfall early in the wet season and less rainfall late in the wet season, and vice versa, likely impacting the grouping patterns observed at Mushara. Thus, future work should break up the broadly defined wet and dry season categories into four, narrower categories including early-wet, late-wet, early-dry, and late-dry seasons. ENP also experiences oscillating periods (2–20 years) of either above or below-average rainfall [46], highlighting the importance of collecting detailed, long-term data on waterhole use by elephants. Rainfall and season play a critical role in shaping elephant lives in Etosha [2,4,10]. In the face of climate change and a predicted 10–20% decrease in rainfall in the ENP region [47], a more nuanced understanding of the relationship between elephant grouping and rainfall will better aid in their management within the confines of the park.

4.2. Diurnal Grouping Patterns

Diurnal occurrences varied significantly among group types (Figure 5). None of the group types visited Mushara frequently in the mornings. During the dry season, mornings in ENP are cool and elephants might defer their drinking and mudding needs until later in the day. Additionally, mornings are often windy in the open clearing, which impairs the elephant's primary senses, hearing and smell; thus, they are less likely to leave the safety of the brush until the winds have died down later in the day. Wind avoidance was best exemplified when lone males or small family groups would run to the waterhole, drink quickly, and then run back out of the clearing after only a brief time at the waterhole (personal observation, J.L.B. and C.E.O.-R.).

Since Mushara is in an area largely dominated by sandveld, characterized by smaller trees and shrubs [31], elephants are likely to arrive in the Mushara area during midday for both water and long-term forage. In Etosha, elephant preference for grasses peaks in the early morning and in the later afternoon (around 5 p.m.), while preferences for long-term forage peak midday [10]. Elephants might also arrive at Mushara in the heat of the day when the windspeed is usually low. Males and families are looking to cool themselves down during this time and may be less likely to discriminate about who they are socializing with. Thus, environmental pressures may influence some of the grouping patterns at Mushara.

In contrast to all other group types, family groups most often visit Mushara in the afternoon (Figure 5) and into the night (personal observation, J.L.B. and C.E.O.-R.). In ENP, family groups prefer to stay near surface water in the evenings (around 7 p.m. and later) [10], spend more time in the veld during the day, and visit Mushara at night near the permanent source of surface water, likely explaining the low number of family observations (5.9%). Finally, family groups might also travel more in the night when sounds travel longer distances and elephants can better hear other elephant groups and threats from farther away [48]. Since family group occurrences are more dependent on the needs of calves and their mothers, camera traps with night-vision capabilities might be needed to better assess group patterns at Mushara.

4.3. Undergraduate Students as Reliable Observers in Camera Trap Photo Data Collection

Inter- and intra-rater reliability was high for elephant group size and group type. As undergraduate students, the research assistants were considered non-specialist observers. All research assistants had some biological sciences coursework but no knowledge of elephant ecology or formal research experience, similar to volunteer students who collected elephant behavioral data from videos in Webb et al. [26]. Webb et al. [26] found reasonably high inter- and intra-observer reliability, where most of the behaviors assessed were categorized as excellent (ICC $\geq$ 0.75). The results of both this study and [26] suggest that with some training, undergraduate students can be reliable observers for elephant camera trap data collection such as counting elephants and determining group type, relieving some of the workload from park managers. Further, where funding is available, including students enrolled in colleges and universities in countries where camera trap data are collected would provide an excellent opportunity to include aspiring wildlife researchers or park rangers by giving them a chance to participate in research and interact with park management.

4.4. Additional Considerations of Camera Trap Methodology

During the study period, we had two camera traps set up: one fully battery-powered and one solar battery-powered that was charged with a small dedicated solar panel. The battery-powered camera trap served as a backup, which in this particular year was needed since the solar-powered camera trap failed due to a faulty wire between the solar panel and battery. Researchers might consider having a backup camera trap in very remote areas, one of each type, due to the complementary advantages of each system. In addition, there are wireless systems that allow multiple camera traps to run independently at separate locations, where all data from each camera are downloaded to a wireless hub through a remote repeater, with the advantage of not requiring large storage onsite. This would be ideal in remote areas where sensitive or rare species might use multiple paths, making monitoring more challenging. In addition, regular access to camera traps in remote areas could be challenging.

Battery-powered camera traps are a good option in areas where solar-powered camera traps are difficult to secure. Battery-powered camera traps might be suited for areas where resources are more limited, but personnel are available to manually change batteries and swap out data storage cards. Solar-powered systems have the advantage of running continuously, without the need to change out batteries. Without a mechanism to upload to a server, however, the chip would have to be swapped out at least on an annual basis, depending on the number of images desired per day. Overall, the configuration of a specific camera trap methodology should be carefully considered based on battery life and storage capacity, in addition to any other unique attributes of the study location and research questions.

5. Conclusions

Research on elephant movement and grouping patterns has largely relied on aerial surveys and GPS collars. Both methods are labor intensive, require multiple stakeholders, and in the case of collaring, can be dangerous for elephants and people. Camera traps provide a low-cost, low-effort alternative, with the potential for greater involvement of non-specialist observers. Our results support previous findings of seasonal and diurnal grouping patterns in Etosha [2,4,5,10], highlighting the potential for camera trap use in ENP as a complement to existing methodology. An added advantage of the solar-powered camera trap is the continuous, year-round access to grouping data of elephants and other animals. For large parks with remote regions, camera trap data would be invaluable for monitoring lesser-known populations. Our results support the expanded use of camera traps in countries with free-ranging elephants to promote more localized management practices, based on the understanding that elephants show marked interindividual variation in movement and grouping patterns [6,10,11,13]. Finally, given the success of using undergraduates for data collection both here and in previous work [26], we propose a continued use of non-specialist observers in elephant camera trap research to relieve some of the workload of park managers and researchers, as well as provide students an opportunity to contribute to important conservation efforts.

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Data Availability Statement: Publicly available datasets were analyzed in this study. These data and associated code for analysis can be found here: https://github.com/Utopia-Sci-Lab/Elephant-Camera-Trap-Research-Mushara-ENP-Namibia (accessed on 16 October 2023).

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Appendix A

Table A1. Total number of photos per group type (n), split up by season and time of day. The total number of photos collected across all groups is 4366.

Group Type	Season	Time of Day			Total Photos per Season
		Morning	Midday	Afternoon	
Solitary male (n = 1197)	Wet	208	228	91	527
	Dry	184	262	224	670
Male (n = 2043)	Wet	258	337	77	672
	Dry	278	842	251	1371
Family (n = 248)	Wet	6	11	41	58
	Dry	16	66	108	190
Mixed (n = 878)	Wet	42	63	34	139
	Dry	86	487	166	739

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