Elk Bugling Chronology using Acoustic Monitoring Techniques

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Abstract: Elk (*Cervus canadensis*) populations generate substantial interest from wildlife viewers and hunters alike. The Eastern elk subspecies (*C. c. canadensis*) once roamed the eastern U.S. including Tennessee until their extirpation in the mid-1800's. The Tennessee Wildlife Resources Agency reintroduced Manitoban elk (*C. c. manitobensis*) onto the North Cumberland Wildlife Management Area in Tennessee from 2000–2008. During the fall rut, bull elk vocalize using bugles to indicate both aggression and mating intention. Determining elk bugle chronology and patterns could provide an efficient way to determine peak rut and enhance elk viewing and hunting. We used acoustic monitoring during 2021 to determine peak rut activity via bugle recordings at the North Cumberland Wildlife Management Area across seven sites to provide information on breeding chronology and peak elk viewing. We found overall peak bugling occurred from 23 September to 10 October with an additional peak from 17 to 19 October. Bugling peaked during 7:00–9:00 and 18:00–20:00 for all recorders combined. Based on calving dates recorded in 2024 and backdating to conception in fall 2023, this bugling timing was consistent with a typical peak rut. Acoustically monitoring elk populations during the rut may help managers to assess breeding season chronology and estimate calving dates. Acoustic recorders can also record detection of other vocal animals in the area which may influence elk behaviors and movements.

Key words: breeding season, bugle, *Cervus canadensis*, vocalizations

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The recreational opportunities related to elk (*Cervus canadensis*) viewing and hunting are of high economic value and public interest in much of North America. The U.S. Fish and Wildlife Service estimated that there were 11.5 million big game hunters in the U.S. and that 57% of the U.S. population ≥16 years old watched wildlife (UFWS 2023). Many of these activities centered around elk. In addition to hunting, wildlife enthusiasts travel to elk habitat during their mating season (rut) to hear male vocalizations known as bugles (Schultz and Bailey 1978). Maintaining and enhancing elk viewing and harvest opportunities are important priorities for resource managers in many U.S. states.

The Eastern elk subspecies (*C. c. canadensis*) once occupied the eastern portion of North America until its eventual extirpation in the mid-1800's due to overharvest and habitat loss (O'Gara and Dundas 2002). The last elk reported in Tennessee was killed in 1849 (Ganier 1928). Citizens in the eastern part of Tennessee pushed for elk restoration in 1999 and worked with Tennessee Wildlife Resources Agency (TWRA) to develop a restoration plan. The TWRA released Manitoban elk (*C. c. manitobensis*) from Elk Island National Park in Alberta, Canada, onto the North Cumberland Wildlife Management Area (NCWMA), Tennessee from 2000–2008 (Kindall et al. 2011) to bring back this important part of Tennessee's natural heritage. Successful restoration has led to significant economic benefits. Chapagain and Poudyal (2020) estimated the benefits of elk hunting opportunities in Tennessee alone to be between USD $1.63 million and $2.05 million annually when including travel time. Chapagain et al. (2022) estimated that the total economic value of elk viewing opportunities in Tennessee was as high as $6.95 million.

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Because elk restoration occurred recently in eastern Tennessee, limited information is available about reproductive timing and behaviors. However, this information is vital to timing of hunting seasons and peak elk viewing which occur during the breeding season. Most often, late summer to early fall (August-October) is regarded as the best opportunity for elk viewing and hunting as this coincides with their rut (Bowyer 1981). During the rut, male elk become more visible since they are moving more (Wichrowski et al. 2005) and bugling. Therefore, documenting bugling activity may be a way of tracking reproductive timing.

Bugles are high-pitched vocalizations which typically occur between 1.000 to 7.500 kHz, last 2 to 4 sec, and can be heard several kilometers away (Feighny et al. 2006, Frey et al. 2013). The structure of an elk bugle typically consists of three main segments: the on-glide, whistle, and off-glide (Feighny et al. 2006). Initially, the vocalization is emitted in a low frequency and increases in pitch as it moves to the whistle. The whistle remains steady at a high frequency until it quickly drops into the off-glide which is sometimes followed by 1–5 "grunts" (Feighny et al. 2006).

Although elk vocalizations occur at various times throughout the year, bugling typically coincides with peak hours and dates of the rut (Volodin et al. 2015b). Peak bugling typically occurs in late September and early October although exact timing varies by location (Peek 2003). As an advertisement to females, bugling occurs during the time when females are most active, during the early morning and late evening hours aligning with the crepuscular nature of elk (Struhsaker 1967, Geist 1982, Volodin et al. 2015b).

Besides communicating mating signs to female elk, bugling also provides herding aids for fall harems (Boyer and Kitchen 1987) as well indicating aggression to other male elk also attempting to mate with a bull's harem (de Vos et al. 1967, Volodin et al. 2015a). Bugles intended for male-on-male aggression are typically more harsh than non-aggressive vocalizations and occur at lower frequencies than those intended to signal mating intentions to cows (Feighny et al. 2006). Based on comparisons of bugle frequency to various indicators of physical fitness larger males are more successful in mating and have increased vocal tract length, nutrition, maturity, and muscular strength and endurance (Titze and Riede 2010, Hurtado et al. 2011, Reby et al. 2016, Golosova et al. 2017). Older, more mature males typically bugle more often than younger bulls and are usually more successful in siring calves (Struhsaker 1967, Kie et al. 2013). Cows prefer vocalizations with higher frequencies, potentially indicating better physical condition in males that use higher frequency calls (Charlton et al. 2007, Reby et al. 2010, Titze and Reide 2010). In captive herds, bulls have used higher pitched bugles than those of wild herds, possibly due to increased competition in the captive herds (Volodin et al. 2015b, Golosova et al. 2017).

Given the complex information communicated through bugling, acoustic monitoring of elk populations is an important tool for understanding elk behavior and providing recreational opportunities associated with elk. Previous surveillance studies used acoustic monitoring for elk vocalizations to assess bugling timing, vocalization structures, differences among bull age groups and populations, and indications of physical fitness to cows (Feighny et al. 2006, Volodin et al. 2015a, Volodin et al. 2015b, Reby et al. 2016, Golosova et al. 2017) and observation of mating behaviors during the rut (Morrison 1960, Bowyer 1981, Volodin et al. 2015a). In this study, we used acoustic monitoring to measure peak bugling dates and hours during the Tennessee elk rut. We also assessed calving dates in a later year to assess timing of conception with respect to that of peak bugling. By documenting temporal patterns of bugling, this study provides a timeframe for both prime elk viewing and hunting, which have large economic impacts and natural heritage interests for the state.

Study Area

We monitored elk bugling across the NCWMA (79,318 ha) in the 271,145-ha elk Restoration Zone that spanned Scott, Campbell, Morgan, Claiborne, and Anderson counties in Tennessee during 2021 (Figure 1A; TWRA 2018). The NCWMA is split into five units, the New River, Royal Blue, Sundquist, Highcliff, and the Ed Carter Units. We focused on three of the five units and selected areas due to known elk populations including the Ed Carter Unit (specifically sites Tackett 1 and 2), Sundquist Unit (specifically Elk Viewing Tower Area designated as Tower 1 and 2), and Royal Blue Unit (including Chestnut Ridge, Copperhead, and Massengale). In 2021, hunting was available in all units except for Tower 1 and 2. Historically this area was used for strip, bench, and deep coal mining leaving behind shelves and benches on the landscape. Cabrera (1969) described the NCWMA as a mixed-mesophytic forest. The NCWMA landscape was classified as 86% deciduous forest, 12% openings from reclaimed coal strip mines and fields, and 1% cropland, with a portion of the NCWMA converted to wildlife openings (TWRA 2000).

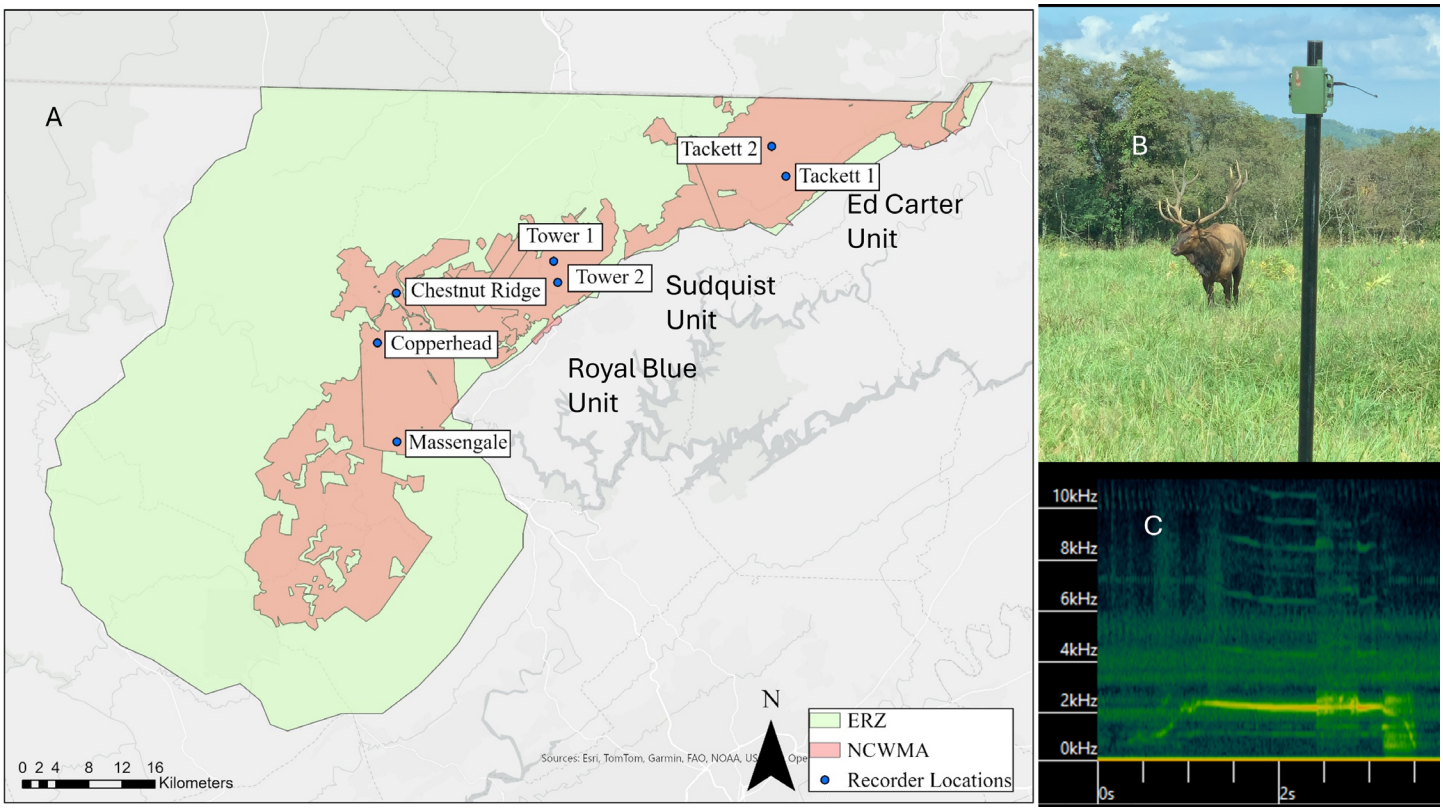

Figure 1. A. North Cumberland Wildlife Management Area, Tennessee within the Elk Restoration Zone (ERZ) with 7 sites monitored with acoustic recorders during fall 2021 to record elk (*Cervus canadensis*) bugling activity. B. Male elk next to post with acoustic recorder. C. Typical spectrogram of an elk bugle. Bugle recorded using Song Meter Mini (Wildlife Acoustics Inc., Maynard, Massachusetts) and analyzed with visualization using Kaleidoscope Pro (version 5.4.7; Wildlife Acoustics Inc.).

Methods

Bugle Monitoring

We deployed seven Song Meter Mini 2 AA recorders (Wildlife Acoustics Inc., Maynard, Massachusetts) on the NCWMA, each with eight AA batteries and a 128 gigabyte SD card. We selected recorder locations based on their levels of bugling activity during the rut in previous years (Figure 1A). We mounted recorders with zip ties on metal t-posts approximately 1.52 m from the ground with the speaker on top of the recorder (Figure 1B). We deployed two recorders in both the Tackett Creek and Elk Viewing Tower sites due to the larger size of the elk management areas. We placed the three other recorders at the Massengale, Chestnut Ridge, and Copperhead sites. Distances between all recorders were > 2 km (closest within-unit distances: 2.09 km between Tower 1 and 2; 3.19 km between Tackett 1 and 2; 5.17 km between Chestnut Ridge and Copperhead; 9.78 km between Massengale and Copperhead; Figure 1A). We placed recorders in open, grassy areas at the highest point within each site, avoiding areas with physical obstacles that could cause issues with the recorders' ability to accurately measure incoming bugles and other sounds. The two recorders deployed at the Elk Viewing Tower had high elk activity and no hunting while the remaining recorders were in hunt zones within the NCWMA.

We deployed recorders from 12 August 2021 to 29 October 2021 and programmed them to record for the first 30 min every hour for 24 h. The gain was set at 18 dB and the sampling rate at 24 kHz per the recorder's default settings. The recording schedule was selected based on available options for the recorders; we chose not to record continuously in order to better utilize battery life. We replaced batteries every 2 weeks and collected SD cards at the end of every month.

Bugle Analyses

We uploaded audio recordings and analyzed data using Kaleidoscope Pro (version 5.4.7; Wildlife Acoustics Inc., Maynard, Massachusetts) following Wildlife Acoustics recommendations for data classification. In Kaleidoscope Pro, we performed a two-step cluster analysis as is common with studies using noise and vocalizations (Guerro et al. 2023, Berman et al. 2025, Bowler et al. 2025).

Cluster analyses statistically group data based on similar characteristics shared among data types; in this study we used Kaleidoscope's cluster analysis algorithm which groups noises based on spectrogram patterns. In a preliminary cluster analysis, we found that bugles recorded at the NCWMA predominantly fell between 0.000–4.000 kHz, fitting within bugle ranges reported in the literature (Feighny et al. 2006, Frey and Reide 2013). Therefore, for the cluster analysis we filtered out sounds that occurred outside above 4.000 kHz. We checked the first 20 recordings for each cluster for bugling activity through visual spectogram identification of bugles which we then confirmed by listening to the audio recording. If the first 20 recordings for individual clusters were bugles, we gave them a "bugle" classifier label. We gave classifier labels to other sounds like wind, wild pig (*Sus scrofa*), American black bear (*Ursus americanus*), spring peeper (*Pseudacris crucifer*), coyote (*Canis latrans*), human, and cricket (Gryllidae) noise during the first step to inform the second analysis of clusters. If one of the recorders' initial analyses did not accurately cluster bugles, we still gave sound bites classifier labels for the sounds listed above to better inform the algorithm for the second cluster analysis. For the recorders that successfully clustered bugles during the first analysis, we completed a second analysis using the classifiers and clusters created from the first analysis to inform the second algorithmic grouping of sounds. In the second cluster analysis, the software automatically labeled clusters as "bugle" if the audio recordings matched the recordings and clusters classified as such in the initial analysis. We assessed the first 20 recordings for each of the newly categorized "bugle" clusters for bugling activity and we included in final analyses if we detected elk vocalizations. If no bugles were correctly clustered or classified during the first or second analysis, we manually went through each recorded sound bite from each cluster in Kaleidoscope Pro and found, labelled, and counted bugles by hand.

Following the two-step cluster analysis, we counted the number of detected bugles for each recorder. We categorized bugle recordings temporally by day and hour for each month surveyed. We visually plotted the number of recordings in each of these categories through time to assess peak bugling dates for each recorder. Similarly, we examined daily bugling activity patterns by calculating the number of bugles recorded. We plotted the number of bugles per day and per hour for each recorder and for all recorders combined to investigate temporal patterns of elk bugling from visual assessment of the pattern.

Calving Timing Estimation and Backdating to Conception

We recorded birth dates of calves born in 2024 to verify breeding chronology, which has appeared consistent across years. We acquired calving data from an ongoing companion study using vaginal implant transmitters (VITs, Lotek Wireless Newmarket, Ontario, Canada) paired with LiteTrack Iridium Series GPS collar with proximity sensor (Lotek) and opportunistic captures of calves in the field. We captured females in 2024 using a net gun from helicopter (Helicopter Wildlife Services, Austin, Texas). The helicopter transported captured elk to a central workup area and where they were immobilized with 2 mL BAM (17.3 mg mL^{-1} butorphanol tartrate, 9.1 mg mL^{-1} azaperone, 10.9 mg mL^{-1} medetomidine; Wedgewood, Swedesboro, New Jersey). We determined pregnancy using ultrasound (EVO III portable ultrasound and linear rectal transducer, Choice Medical Systems, St. Petersburg, Florida). We paired the VITs with the collar in pregnant females. These transmitters sent a signal when the VIT did not move after an hour, and the temperature changed. We also captured calves during routine travel in the elk zones primarily close to Tower 1 and 2. These calves were considered as recently born based on body mass (15–22 kg), behaviors (limited movement and hiding behaviors), and general morphological characteristics (Hudson and Haigh 2002). We used 247 ±3 days for general gestation time (Hudson and Haigh 2002) to backdate when conception likely occurred. We calculated mean (SE) julian date of birth event.

Statistical Analysis

We obtained photoperiod data for Oneida, Tennessee for the dates of bugle recording (timeanddate 2025). We converted day length into total min per day. We obtained high and low temperatures and precipitation data from the National Weather Service for 2021 using weather data from Oneida, Tennessee (National Weather Service 2025).

We examined the effects of daily high and low temperature, daylight (min), and peak breeding time range (calculated from calving dates) on daily bugle counts in R (R Core Team 2025) using generalized linear mixed models (GLMM; glmmTMB package, Brooks et al 2025). We used site as a random effect and excluded days when recorders were not functioning, then tested for overdispersion with a Poisson distribution including all covariates (McGillycuddy et al. 2025). Following the check for overdispersion, we used the negative binomial distribution to account for seasonal patterns causing non-linearity in bugle count results. We applied a negative binomial approach to account for overdispersion and non-linear seasonal changes. We used the range of peak breeding to designate this factor. We created a global model with all covariates, models for each individual covariate, and a model combining photoperiod and peak breeding covariates. We assessed models using Akaike information criterion (AIC) and considered models with $\Delta AIC < 2.0$ as informative. We then examined

beta (β) estimates, standard errors (SE), and 95% confidence limits with the AICcmodavg package in R for supported variables in the top model (Mazerolle 2023).

Results

Bugling Results

During late August through mid-September, we did not replace batteries. This created a 17-day data gap (30 August 2021 to 15 September 2021) for four of the recorders (Tower 1, Tower 2, Chestnut Ridge, and Massengale). For the same reason, the Copperhead recorder did not record from 29 August 2021 to 15 September 2021 and Tackett 2 from 1 September 2021 to 15 September 2021. The Tackett 1 recorder did not store any recordings until 16 September 2021 due to physical interference from elk dislodging the microphone or monitor. The Chestnut Ridge and Tackett 1 recorders were unable to record sounds consistently as bull elk rubbed their antlers against the t-posts, dislodging the recorder batteries and SD card.

Throughout the study period, we captured 8919 recordings (30 min each) with the seven recorders. From these 30 min recordings, we recorded 28,853 bugles (Figure 1C, Figure 2). The Tower 1 recorder captured most bugles (total = 18,728) followed by Tower 2 (7927; Figure 3), Chestnut Ridge (1331), and Tackett 1 (820; Figure 4). We counted bugles manually for the Tackett 2, Massengale, and Copperhead recorders because they did not record enough bugles for Kaleidoscope Pro to be able to form clusters. We recorded nine bugles for Tackett 2, 17 for Massengale, and 21 for Copperhead (Figure 5).

Peak bugling occurred from 23 September 2021 to 10 October with an additional peak from 17–19 October (Figure 2). Although lower in bugling activity, Tackett 1 appeared to have an earlier peak bugling compared to the Tower sites (Figure 3, Figure 4). We did not see definitive timing patterns for Tackett 2, Massengale, and Copperhead because of limited number of bugles (Figure 5). Although elk bugling occurred at all hours, peak bugling was between 7:00–9:00 and 18:00–20:00 (Figure 6). Chestnut Ridge had a peak at midnight (Figure 6).

Calving Dates and Conception Date Estimation

We estimated peak mating occurred from 26 September through 7 October 2023 (range among sites: 17 September through 2 November 2023) based on eight birth events (three from VIT alerts and five opportunistic captures estimated to be 1 or 2 days old). The mean conception date was 3 October (SE = 4.8 days), and the mode was 26 September. Calculated conception dates were similar to peak bugling periods.

The full Poisson GLMM had no support (Table 1) and overdispersion was present (dispersion statistic of 34.76 compared to an expected dispersion value < 1.0 if the Poisson model was adequate). The negative binomial GLMM including peak breeding and daylight length had the most support among models examined (Table 1). As daylight increased there was a slight increase

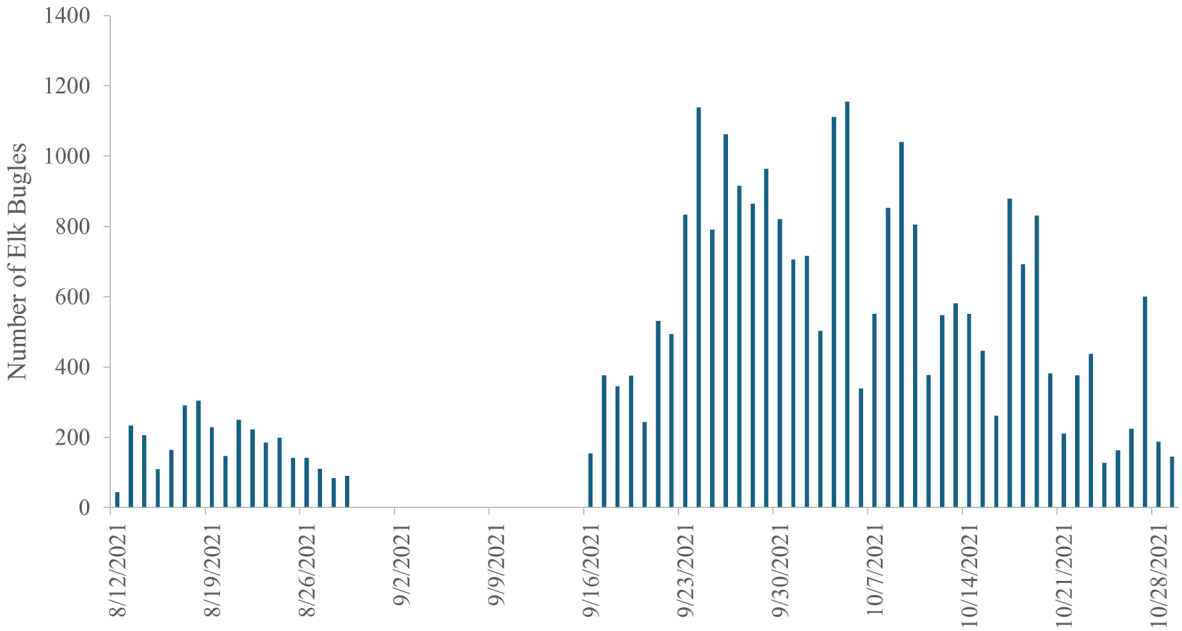

Figure 2. Number of elk (*Cervus canadensis*) bugles detected per day during the study period for all recorders across all units at North Cumberland Wildlife Management Area, Tennessee in fall 2021 (28,853 total elk bugles). Elk hunting seasons in 2021 (excluding Tower 1 and 2) occurred from 25 September – 03 October for Archery (four hunters), 04 October – 10 October for Young Sportsman (three hunters), and 11 October – 17 October for Gun, Muzzleloader, and Archery (three hunters).

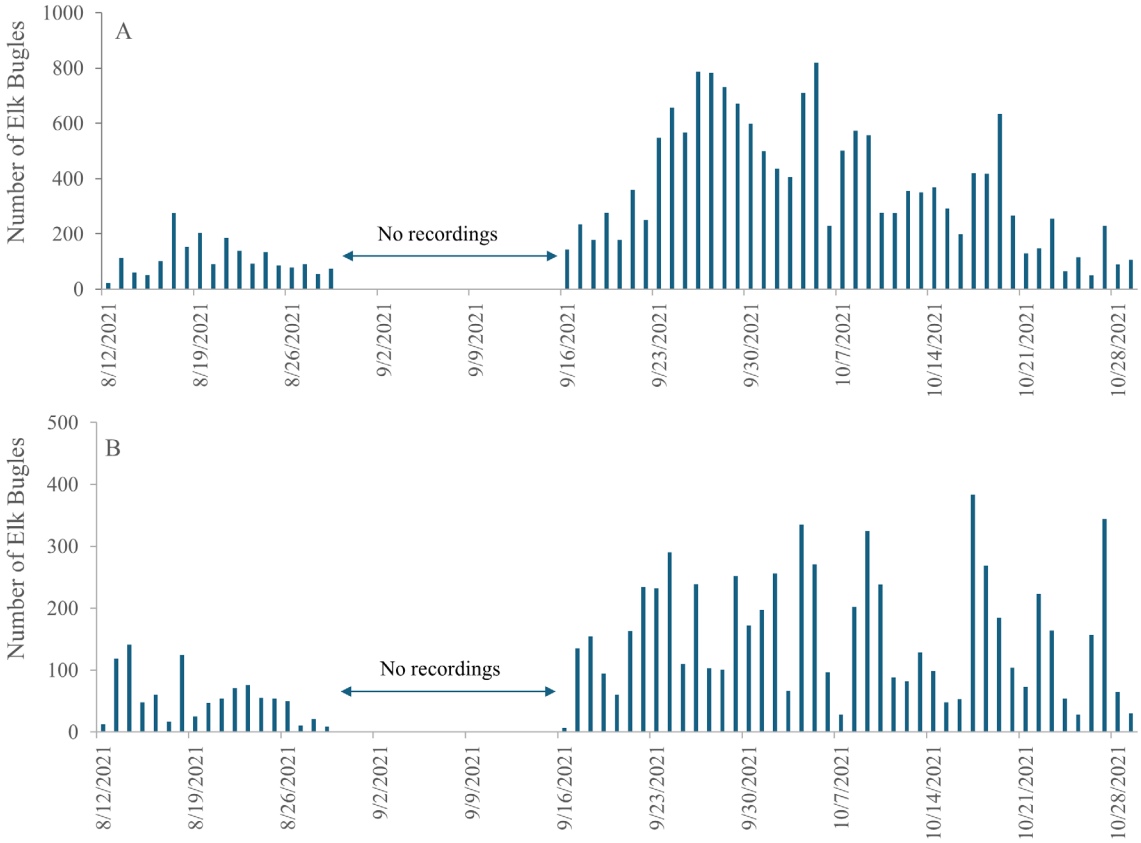

Figure 3. Number of elk (*Cervus canadensis*) bugles detected per day for Tower 1 (A; 18,728 bugles total) and 2 (B; 7,927 bugles total) in the Sundquist Unit at North Cumberland Wildlife Management Area, Tennessee in fall 2021.

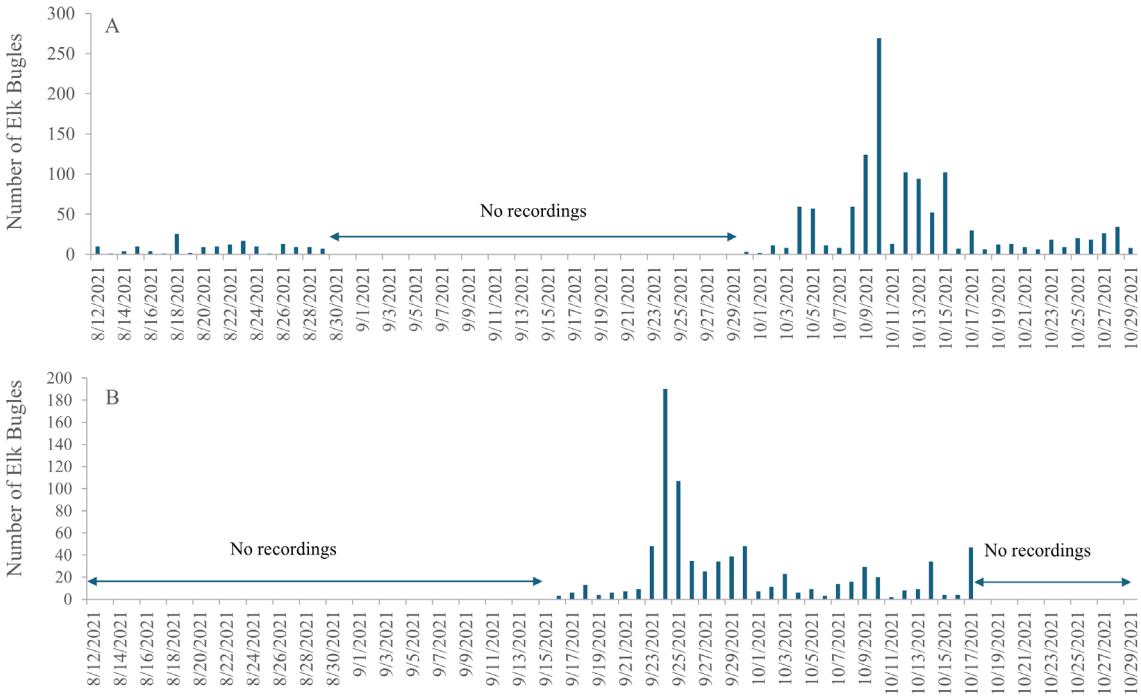

Figure 4. Number of elk (*Cervus canadensis*) bugles detected per day for Chestnut Ridge (A; 1,331 elk bugles total) in the Royal Blue Unit and Tacket 1 (B; 820 elk bugles total) in the Ed Carter Unit at North Cumberland Wildlife Management Area, Tennessee in fall 2021.

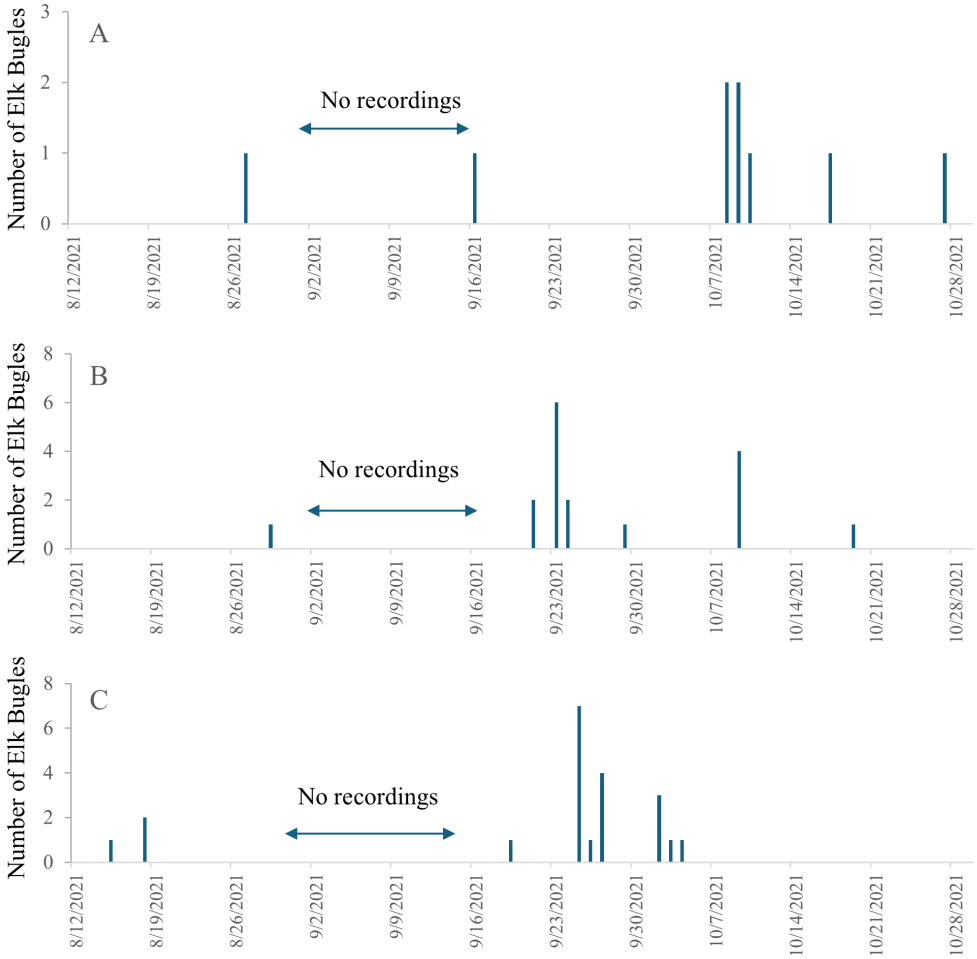

Figure 5. Number of elk (*Cervus canadensis*) bugles detected per day for Tacket 2 (A; 9 elk bugles total) in the Ed Carter Unit and Massengale (B; 17 elk bugles total) and Copperhead (C; 21 elk bugles total) in the Royal Blue Unit at North Cumberland Wildlife Management Area, Tennessee in fall 2021.

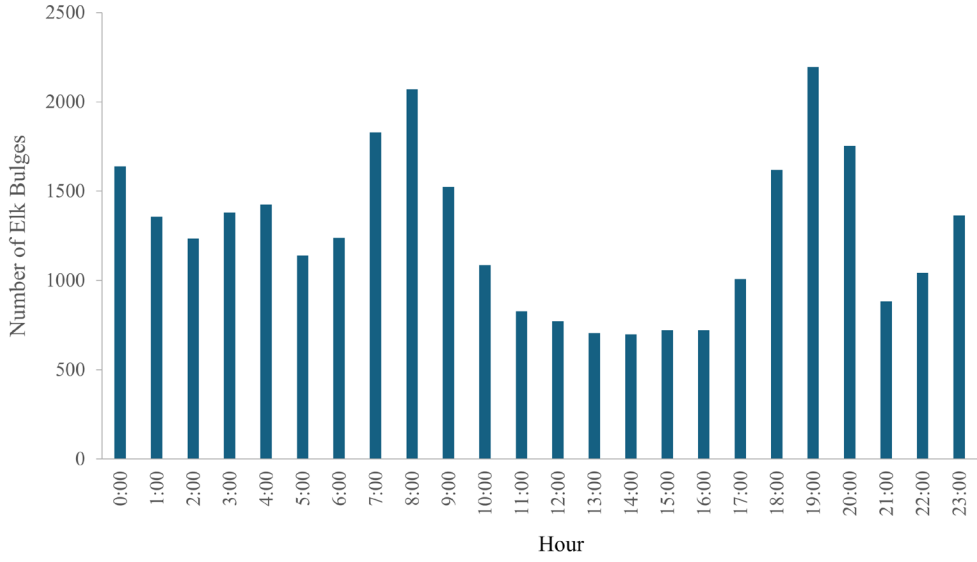

Figure 6. Number of elk (*Cervus canadensis*) bugles detected per hour for all units during the study period (12 August – 29 October 2021) at North Cumberland Wildlife Management Area, Tennessee.

Table 1. Model selection results for elk (*Cervus canadensis*) bugle count data with variables including daily maximum and minimum temperature (C), daily precipitation (cm), daylight length (min), calculated peak breeding dates (from calving data collected in 2024 with backdating to conception), and site as a random effect at North Cumberland Wildlife Management Area, Tennessee in fall 2021. All models were fit with the negative binomial distribution except for the final model, which used the Poisson distribution. Results for each model include log-likelihood (*LL*), Akaike's Information Criterion (AIC), difference in AIC compared to model with lowest AIC value (ΔAIC); AIC model weight (*w*), and number of parameters (K).

Model	*LL*	AIC	ΔAIC	*w*	K
Daylight + Peak breed	−1413.62	2837.24	0.00	0.85	5
Daylight + Max temp + Min temp + Precip + Peak breed	−1412.34	2840.68	3.44	0.15	8
Peak breed	−1431.91	2871.82	34.58	0.00	4
Max temp + Min temp + Precip	−1461.34	2934.68	97.43	0.00	6
Daylight + Max temp + Min temp + Precip + Peak breed (Poisson)	−8209.98	16433.95	13596.71	0.00	7

in bugle counts (daylight β estimate = 0.023, SE = 0.004; 95% CI = 0.016–0.030). During the peak breeding period, we collected over four times more bugles than during the non-peak breeding dates (peak breeding β estimate = 4.450, SE = 0.435; 95% CI = 3.597–5.301).

Discussion

Acoustic monitoring can be useful for evaluating elk breeding, measuring species interactions, and assessing community biodiversity. Acoustic recording of bugling provides valuable information for the public on peak elk activity and behaviors to better plan for viewing and hunting. Using our methodology, we were able to determine peak timing for elk vocalizations in the NCWMA. Peak bugling coincided with the 2024 breeding season and the 2021 elk hunting season for this area (27 September to 17 October). Although we missed some periods of recording due to battery loss, this loss of data likely occurred when bugling was lower since our observed bugling peaks corresponded well with 2024 calving dates based on a 247-day gestation period. The timing of peak bugling we observed also aligns with peak breeding season for the adjacent Kentucky elk population from late September through October (Kentucky Elk University 2025).

Hudson and Haigh (2002) described elk rut in general being related to the autumnal equinox, but timing is also affected by nutritional status. We found a small positive relationship between longer daylength and number of elk bugles per day which may be related to the missing data for the beginning dates and peak bugling occurring during those longer days. Bugling declined as the rut extended into the shorter daylengths, further supporting photoperiod as a driving factor for rut timing (Hudson and Haigh 2002). Therefore, day length and peak breeding were the main drivers of bugle numbers over time. We did not see effects of temperature or precipitation on bugling.

In our results, visually there appeared to be a difference between the peak bugle timing at Tacket 1 in the northern Ed Carter Unit compared to the Tower sites in the Sundquist Unit. However, with differences in data collection and overall numbers of bugles it is not possible to make a definitive conclusion that breeding chronology differed between the two sites. Further work addressing bugling chronology for each area over time is needed to examine potential differences and effects of environmental factors on breeding timing. Similarly, monitoring peak bugling peaks could be used to assess whether breeding chronology changes with reintroductions of elk from other populations.

Kaleidoscope's cluster analysis works by detecting and grouping audio clips with similar visual structures, numbering clusters by commonality where the most common sound is clustered first, the next most common second, etc. Because of this method, areas with high amounts of auditory activity were likely to have a greater number of ill-defined clusters than other areas with fewer clusters. This circumstance could have affected our analyses as the elk viewing tower was a noisier area due to higher traffic by other animals and humans and their associated sounds (e.g., vehicles, humans imitating bugle calls, and human speech). The Tower 1 recorder captured sounds from humans, vehicles, insects, frogs, birds, coyotes, and bears. Some of these sounds were visually similar to elk vocalizations in timing and frequency but we could easily verify via sound. Although rare, we may have included some of the other sounds in bugle clusters and vice versa. For all recorders except Tower 1, we manually identified these sounds and we did not include them in the total bugle count. With the Tower 1 recorder, we captured over 18,000 sound clips categorized as bugles which we did not manually check for accurate clustering due to large quantity of clips contributing to increased accuracy of clustering. The pattern of seasonal changes in bugling from this recorder was consistent with patterns from the other six recorders.

In 2021, the Tower recorders were in areas not hunted. The general pattern of bugling was the same for the areas hunted versus not hunted although confounded by elk population numbers. There has historically been more elk activity in these non-hunted areas. However, there were only 10 successful hunters across the hunted areas from 15 September through 17 October 2021 so hunting may

not have been a huge influence across the zone. The elk zone also has high off-highway vehicle (OHV) use. Human disturbance, including hunting, can affect elk behaviors and movements, as Smith et al. (2021) found male elk responded most to hunting during diurnal hours and during rifle season compared to archery season. Female elk also responded during daylight hours to hunting pressure and avoided forage, roads, and trails which could have implications for nutritional status (Spitz et al. 2019). We do not have any indication that OHV use or hunter effort affected bugling in Tennessee. As with other factors, future studies in our area are needed to assess interactions between human activity and elk activity.

As noted above, we detected species other than elk on our recorders, including wild pig, coyote, black bear, crickets, birds, and frogs. Although the detection of other species was limited at most sites, at Copperhead we recorded wild pig activity along with elk vocalizations in nearly equal amounts and at opposing times (21 elk bugles, 22 wild pig vocalizations). In our study region, as is being demonstrated globally (e.g., Sugai et al. 2019, Wood et al. 2024, Scarpelli et al. 2026), acoustic monitoring can help managers detect invasive species and be an efficient tool for monitoring biodiversity.

While further work is warranted, results from our acoustic monitoring of bugling provide important information to share with the public interested in elk-related recreation. Providing information on bugling chronology can aid hunters interested in maximizing opportunities for harvesting bull elk and support recreational viewing of, and listening to, elk in the protected zones. Acoustic monitoring is also useful for detection of other wildlife species coinciding with elk in the area which could affect elk movements and behaviors.

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