AN ABSTRACT OF THE THESIS OF

Gail J. Woodside for the degree of Master of Science in Rangeland Ecology and Management presented on November 9, 2010. Title: Rocky Mountain Elk (*Cervus elaphus nelsoni*) Behavior and Movement in Relation to Lunar Phases.

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Douglas E. Johnson

Two small herds of Rocky Mountain (*Cervus elaphus nelsoni*) cow elk were, collared, observed, and spatially mapped for 10 continuous six day trials, conducted during 2008-2009. Five trials occurred during full moon periods and five trials during new moon periods. The elk were collared with 1 second interval GPS loggers which recorded Latitude, Longitude, Elevation, Velocity, and Fix Quantity. Data were analyzed for daily and hourly distance traveled, and time spent moving and stationary. To avoid accumulating GPS errors, travel distance was calculated by summing distances between GPS locations with a non-zero, Doppler based velocity. Data was then partitioned into day and night intervals defined by civil twilight. We addressed the question of whether elk move more during full moon or new moon phases. All statistical analysis were conducted using SAS Proc GLM with Julian day as a covariate to remove seasonality. Elk mean travel across all trials was 6.75 km per day. Nighttime mean travel was 0.29 km/hr. Elk travel was similar at night and during the day whether there was a full moon or not.

Rocky Mountain Elk (*Cervus elaphus nelsoni*) Behavior and Movement in Relation to Lunar Phases

by
Gail J. Woodside

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APPROVED:

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Gail J. Woodside, Author

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discharge our roles as true warriors within our own right and obligation as caretakers of this earth and all of her relations.

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work we want to accomplish on this journey through life together. I love you William,

I am coming HOME.

CONTRIBUTION OF AUTHORS

Gail J. Woodside was involved with the experimental design, data collection, data analysis, GPS analysis, and writing of each manuscript. Dr. Douglas Edward Johnson was involved with the experimental design, data collection, data analysis, GPS analysis, and writing of each manuscript. Dr. Pat E. Clark was responsible for collar design. Brian Dick, USFS, was responsible for technical assistance with the elk and other needs at the Starkey Experimental Forest and Range. Michael Johnson, University of California Santa Barbara Department of Physics, was responsible for designing the Animal Movement Classification Tool and other algorithms used for this study.

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DEDICATION

This thesis is dedicated to all women and men who have survived and conquered domestic abuse, be it physical or mental. We all stand together, likened to a fortress, in the face of adversity never blinking an eye.

Chapter 1

Introduction and Literature Review

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Introduction and Literature Review

The Importance of Significance

Nothing is Static in Nature, it is a living breathing entity that consumes and creates energy, moves and walks across the landscape, rebuilds itself, and provides nourishment, it is the force that drives life as we know it, as with all things in nature, the earth mother derives the movement in rhythm with the climate, elevation, aspect, temperature, lengths of day, precipitation, and soil in relation to geologic strata and most recently pollution (Aschoff 1965) (Cajete 2000).

Nothing is insignificant in Nature as well, and must remain in constant balance with the movement of natural things as they cover and change the landscape of the earth. As human beings, we must remember, that something we consider as insignificant usually is the most important piece of the message to understanding life forms and the niches in which they live. Removing the insignificance may cause an unbalance which can lead to entropy.

As scientists it is sometimes easy for us to forget how important balance and significance are as we move across the landscape, changing it and manipulating it in efforts to help restore what has already degraded. For millennia people have been moving across the landscape in positive and negative ways, with today's loss of resources it is important for everyone to move positively across the landscape keeping all balance in nature. This relationship with the earth must be more carefully tended by scientists, because the power we carry in academia, government, and the private sector could alter the world as we know it, therefore making us the caregivers of sacred universes within and around our own home known as Earth.

When I was asked if I would consider this assignment; working with elk; I asked myself about the eco-philosophical relationship which I was embarking on (Cajete 2000). I knew that my interactions with such great beings needed to fit within the realm of low impact observances. I also knew that those interactions and observances were not limited with the elk themselves but with the surrounding flora and fauna and the rhythms in which they exist. There were many questions which entered my mind in regard to the actual impact that I would have while studying them. One part of me was ready to begin an incredible journey, the other part of me was wondering how much I may alter the scientific research with my presence, and another part of me thought about the spiritual realm and scientific connectivity of the seen and unseen while conducting this research.

These questions were important to me as I view the world around me in a holistic perspective always trying to search for a balance between traditional scientific knowledge paired with western science. I thought about the words Linda Moon Stumpff shared in a recent article relating to American Indian perspectives on theory and action in wildlands:

> The cultural significance of wilderness encourages a balancing relationship between humans and nature. It is the primary reason why involvement by indigenous people is critical to future and existing initiatives to sustain wilderness ecosystems.

I thought about my grandmother who believed that combining the old and the new ways of knowing was the only way in the future we could preserve the world as we know it. I also talked with my parents and I realized that the research and the importance of this study would educate many and the resulting information may help ecologists gain a better insight of elk movement and behavior by understanding the delicate balance in which they exist.

Landscape and Movement

When we think of movement across landscape we first need to define what landscape is, as well as educating people about landscape and its relationship to rangeland. Rangeland is defined by Oregon State University, Department of Rangeland Ecology and Management as land which provides quality grazing for wildlife and livestock, another definition states that rangeland is a land use or land cover classification designation utilized for remote sensing (Eastlick 2007) (NASA 1996). Rangelands are also unimproved or undeveloped land and can contain grasslands, woody savannahs, and mixed shrub meadows with riparian uplands and lowlands. For the purpose of this research study, rangelands not only provide wildlife habitat but the area is also geographically utilized for spatial analysis.

Landscape is usually considered a large expanse of land that is extensive and can be seen from a single viewpoint (Webster 1996). The use of landscape, landscape ecology, and the movement of elk over the landscape is the main foci on which all research was conducted. These observational collections required human observation as well as global positioning systems (GPS) to answer the questions in this study.

Oral traditions regarding elk have long been spoken in relation to human survivability and natural movement across landscape. The complex ecological cycles of knowledge provided in oral traditions can aid in a better understanding in animal movement (Stumpff 2000). The people are raised with an internalized respect and knowledge of the elk and deer, and how they are related to them (Stumpff 2000). They have learned that the elk know when to stand up, to lay down, how to manage energy, and whether they need to migrate from summer to winter ranges, or remain within small niche systems (Nelson and Leege 1982).

Circadian Rhythm

Elk behavior is linked with circadian rhythm. Circadian rhythm is a type of cycle that governs the biological clock over twenty four hour periods. Humans and elk share this type of biological fine tuning which is connected to lengths of day and night or chronobiology, and has been around since pre-history (wordiQ.com 2010). It has been rumored that this type of biological clock has always been useful to hunters, using it to pace animal behavioral patterns for hunting knowledge and in hunting societal ceremonial practices. Circadian Rhythm is also connected with hormonal production, brain wave capacity, environment, and sleeping and eating patterns (American Heritage Science Dictionary 2010) (wordiQ.com 2010).

Animals will move in rhythms which fluctuate with the earth's rotation within a 24 hour period (Aschoff 1965). Some rhythms vary but are always associated with two frequenting peaks of activity associated closely with dawn and dusk. Aschoff investigated the bimodal patterns of animals moving under natural conditions and how illumination affected their rhythmic movements. Elk are one of the many species who are affected by illumination of lunar phases and by the oscillation of the earth's rotation.

I was always told that elk move in circles or small migrations over landscape every seven to nine days, while grazing and raising young. Migrations of these types allow for optimal advantage for quality forage and lower mortality rates due to predation (White et.al. 2010). According to my family's oral traditions the knowledge of these movements allowed for correct timing to take animals during the hunt. I tested this advice by watching a wild herd of cow elk (containing a few young males) outside the Starkey Experimental Range. I determined that they did in fact circle to different pastures located between Starkey Experimental Range, Ukiah, and Lehman Hot Springs in nine day intervals. However, small circular migrations do not necessarily mean that elk migrate long distances, and only some species will develop this trait depending on geographic or elevative seasonal changes (Bryant and Maser 1982).

Eye Acuity in Ungulates

Our objectives were focused on elk moving under lunar phases during the day and night. With these objectives in mind, we thought about how clearly the elk see at night, which may or may not influence their movement. According to a study at University of Florida, veterinarians stated that eyes have not changed much over time and that by examining eye structure it is easy to identify whether the host is diurnal, rhythmic, or nocturnal (Samuelson 2010). Humans do not see well during the night and are diurnal; however most grazing ungulates see well at night and can be classified as diurnal and nocturnal.

Rods and cones are what determine eye acuity, with rods allowing you to see better at night and cones allowing you to see better during the day (Samuelson 2010). Reflective tapetum, an eye shine structure, is prevalent in animals which can see well at night, and why the eyes of nocturnal species glow when light hits them after dark.

Jay Neitz, Ph.D., an animal vision specialist at the University of Washington, stated in an online forum that grazing animals have the ability to see keenly at dawn, dusk, and during the night in very dim light respectively.

> ungulate rods predominate even in the central area (of the eye) … include over ninety percent of the total number of photoreceptors in the retinal area of the eye, allowing ungulates to receive nine times more light than a human eye.

Large grazing ungulates can also see ultraviolet light, giving them greater sensitivity than a human eye, allowing them to focus on attributes not seen by humans (Neitz 2004). With this information in mind is it possible that elk may move just as much during the night as the day due to the sensitivity of the retina to retain light.

Global Positioning and Data Logging Collars

The use of global positioning systems (GPS) has contributed to advances in tracking animals for predator prey response, migration, and grazing studies (Clark and Johnson 2009). Many commercial types of tracking systems are used to track large ungulates. Early systems utilized radio collars tracked by fixed wing planes or located on the ground by antenna using compass points (Stehn 1973). As technology has advanced radio-telemetry used signals transmitted from animals to radio towers. The Starkey Experimental Range utilized an A LORAN-C-based telemetry/tower system from 1989 to 2005 (Vavra 2009). The data gathered was loaded on magnetic tape for computer analysis (USDA/USFS 1989). Starkey began using global positioning systems (GPS) in 2005. Radio collars are still used today with varying time lengths of data collection, some collars can be programmed to record at 30 minute positional fixes and others at 5 minute positional fixes (White et.al. 2010) (Clark and Johnson 2009). The data logging global positioning collars used for this study do not utilize radio telemetry and are programmed to record 1-second GPS fixes, over a period of 6.25 days. Data is collected on a Secure Digital memory card located within the collars with store-on-board technology.

Study Objectives

Illumination and circadian rhythm effect elk over all cycles of their movement in relation to the earth’s rotation. All of these cycles occur under lunar phases. The objectives of this study were based on questions surrounding the movements of elk under full and new moon phases and how their movements under these phases were effected during the day and night.

The objectives we formulated for the purposes of this study were:

- The elk activity patterns occurring during a twenty four hour day.
- The spatial patterns of elk movement during the day and night under lunar phases.

Within the realm of these two main objectives we formed questions which we wanted to answer.

- Does elk activity during the day differ from that of the night?
- Do elk travel the same distance during the day as compared to the night?
- Do lunar phases change activity and distance traveled?
- Do the elk move faster at night than during the day or do they move at the same speeds?
- How long do elk remain stationary?

To achieve the objectives of this study we utilized global positioning systems (GPS), geographic information systems (GIS), and field investigations while observing elk. The field investigations allowed us to compare actual observed movements of elk combined with the more advanced global positioning data gathered during the study. Field observation methods are important as some people interested in movements of large ungulates lack the availability of the advanced technology used in this study (Louhaichi 1999). The new advances in global positioning and geographic information allow us to more accurately detect elk activities, including distance traveled and speed at which they move with greater precision (Clark and Johnson 2009) .

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Chapter 2

Travel Activity of Rocky Mountain elk (*Cervus elaphus nelsoni)* Under Lunar Phases

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Travel Activity of Rocky Mountain Elk (Cervus elaphus nelsoni) Under Lunar Phases

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Abstract

Rocky Mountain Elk (*Cervus elaphus*) exist in complex biological and social environments that are punctuated by necessary activities such as foraging, ruminating, and resting. Simultaneously, elk must be alert to potential threats from cougar, bear, and hunting by humans. It has long been understood that elk exhibit circadian patterns. One of the most predictable variables that affect an elk's environment is daylight and nighttime illumination by sequential phases of the moon. We hypothesized that elk could exhibit different innate diurnal movements and spatio-behavioral activities during new and full moon phases that could be quantified using GIS and high-frequency GPS logging technologies. Our study examined 24 hour stationary and travel activity budgets of non-lactating cow elk intensively tracked during 5, week long full moon and new moon periods throughout the summer and fall of 2008 and 2009.

Key Words: elk, movement, diurnal, daylight, GPS, collars

1. Introduction

Elk are an important big game species in Oregon. There are approximately 123,000 elk residing in Oregon, both on the humid western side of the state and the drier areas east of the Cascade Range (ODFW 2010). Their economic importance accrues both from their value as a prized big game species, and from their impacts from foraging. Understanding animal behavior is fundamental to managing both elk/hunter and livestock/elk interactions. Our research was designed to quantify cow elk movement and daily activity patterns during summer and fall under lunar phases.

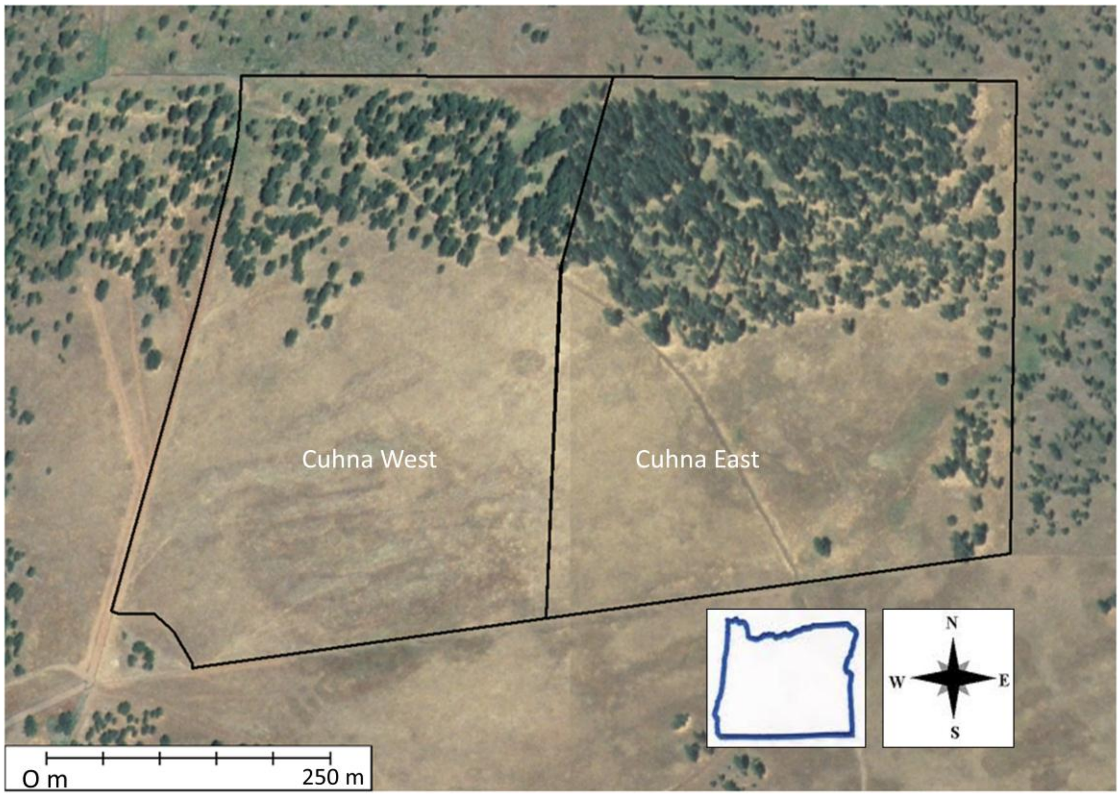
Our goals were to quantify the circadian characteristics and fine scale spatio/temporal behavior of Rocky Mountain Elk (*Cervus elaphus nelsoni*) as detected by high frequency, 1-second GPS logging technologies during periods with and without moonlight. This study also characterized elk travel activity budgets during full and new moon phases, to evaluate whether elk travel more during the day after a new moon or full moon, to determine if the phase of the moon affects full day travel distance of an elk, and to determine if the phase of the moon effects elk activity patterns.

2. Materials and Methods

2.1 Study Area

The study area was located 35 km west of LaGrande, Oregon, USA, at the Starkey Experimental Forest and Range (Lat. 45°.10’-18”N, Long. 118°.28’-37”W) and consisted of two fenced pastures: Cuhna West (16.6 ha) and Cuhna East (17.1 ha) (USDA/USFS 2003).

Figure 2.1 Cuhna East and Cuhna West Pastures located at the Starkey Experimental Forest and Range.



Pastures lie on an upland consisting of dry meadows and forests at an elevation of 1220 m. (4000 ft.) Climate of this site is continental and semi-arid with average annual precipitation of 590 mm (23.3 inches) falling mostly between November and May (Figure 2.1). Mean temperature for September was 13.6°C (56.5°F) and mean temperature for July is 12.2°C (54°F) (Oregon Climatic Service 2007).

Vegetation in the study area pastures was classified into 3 plant communities: dry meadows, Douglas Fir/Oceanspray, and Douglas fir/Elk sedge by the U.S. Forest

Service (Anderson et.al. 1998). Dry meadows consist of shallow rocky grasslands dominated by North African grass, (*Venetenata dubia* (Leers) Coss.), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), Idaho fescue (*Festuca Idahoensis, Elmer*), Sandberg bluegrass (*Poa secunda* J. Presl). Forested sites have open stands of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), Grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.), and Ponderosa pine (*Pinus ponderosa C.* Lawson), with an understory of bluebunch wheatgrass, slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), brome (*Bromus spp*.), common snowberry (*Symphoricarpos albus* (L.) S.F. Blake), Saskatoon serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.), oceanspray (*Holodiscus discolor* (Pursh) Maxim.) and Wild rose (*Rosa sup.*).

2.2 Animals

Ten mature, non-lactating, non-pregnant cow elk were used in this study. These elk were selected from a research herd of more than 60 cow elk at the U.S. Forest Service Starkey Experimental Forest and Range (Wisdom et.al. 1993). The elk were hand-reared by technicians on 3,600 acres of research area enclosures allowing for free range similar to wild distributions with limited public access (USDA/USFS 1989) (1993 Wisdom et al). Each animal was named, ear-tagged, and numbered when undergoing intensive training (neonate-human bonding, halter leading, trailer transport) by Starkey technicians for nutrition studies.

At the time of our study these elk were 17 years old, and weighed between 204 kg and 354 kg (450 and 780 lbs). These animals eventually became less friendly or accepting of human interaction (more similar to wild) and thus became good candidates for this study. Handling and installation of elk GPS collars was conducted by the USFS personnel following standard protocols defined by their Institutional Animal Care and Use Committee (Wisdom et.al. 1993).

Figure 2.2 Cow elk wearing GPS collar.

Just prior to each Trial, the elk were randomly selected, collared, weighed, fitted with GPS tracking collars, and moved to one of the 2 research pastures early in the morning of the first day of the Trial. After a minimum of 6.25 days, elk were retrieved from the research pasture, collars were removed, and post-trial animal weights were recorded. Elk were then released into other grazing pastures until the next Trial date.

2.3 Trials

The experiment consisted of 10 trials of 6.25 days each: representing a total of 169 days of full moon observations and 176 days of new moon observations. There were 2 replicates (pastures) of 5 randomly selected cow elk per trial (Table 2.1).

Table 2.1 Trial Dates and Moon Phases

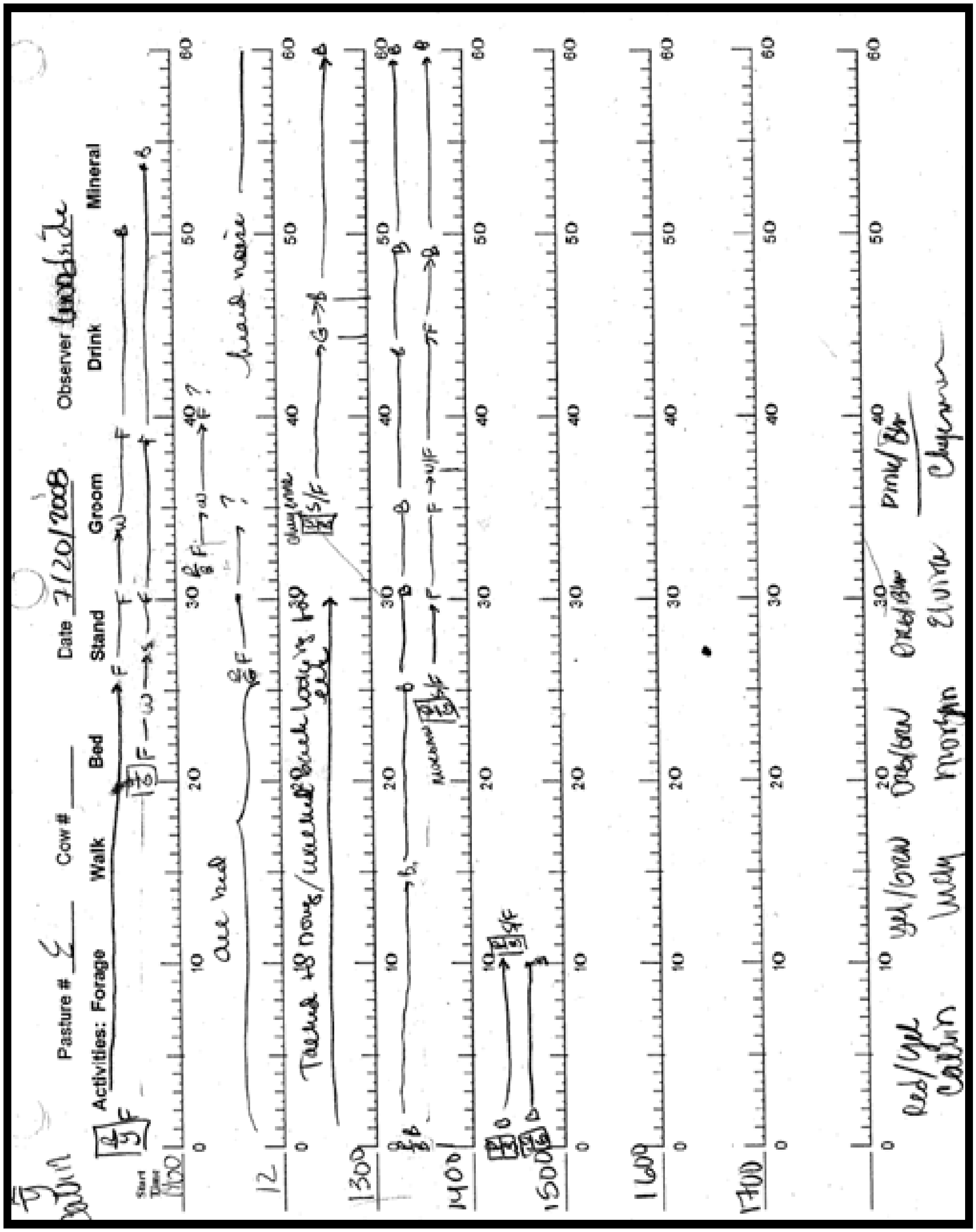
Trial/Moon	Beginning Date	Ending Date
1 - Full	16-Jun-08	23-Jun-08
2 - New	30-Jun-08	7-Jul-08
3 - Full	16-Jul-08	21-Jul-08
4 - Full	11-Sep-08	17-Sep-08
5 - New	25-Sep-08	1-Oct-08
6 - New	20-May-09	26-May-09
7 - Full	4-Jun-09	9-Jun-09
8 - New	18-Jun-09	23-Jun-09
9 - Full	1-Jul-09	9-Jul-09
10 - New	16-Jul-09	22-Jul-09

Trials were conducted during late spring through fall. Each Trial was timed so that either a new moon or full moon would fall in the middle of the Trial. Full moon Trials included monitoring of night skies for percent cloud cover which could affect illumination and elk activity patterns. Weather was also monitored for temperature and precipitation at the Starkey Experimental Forest and Range Weather Station located 2.3 km (1.43 miles) from the center of the study site at a similar elevation. Trial observations of elk spatio/temporal locations and activity types included both global positioning fixes collected on GPS data logging collars and traditional focal animal observations.

2.4 Traditional Focal Animal Observation

Visual field observations of elk activity were collected concurrently with GPS collar data during the 2008 and 2009 Trials. Focal animal sampling methods described by Nelson and Leege (1982) were used to collect these visual observations in the field. Data was collected on a form developed by Dr. David Ganskopp which permitted minute by minute observations of elk in the field, (Figure 2.3) and recorded: foraging, bedding, walking, standing, grooming, and drinking (Ganskopp and Vavra 1987). These observation periods were primarily during daylight hours, where a single (or several) elk was selected and the animal's activities were classified and recorded until the period end or the elk was lost from sight. Local weather and other events of interest were also recorded on field data sheets during focal observation of elk.

Figure 2.3 Traditional field observation sheet developed by Dr. Dave Ganskopp. This image shows minute by minute simultaneous observations of elk.



2.5 GPS Collars

The movements of the ten cow elk were monitored at1-second intervals using GPS data logging collars. (Figure 2.4) these collars weighed 0.9 kg and recorded the following parameter values for each GPS location: latitude, longitude, Universal date and time (GMT), velocity, number of satellites used to obtain the GPS fix, and fix quality at 1-second intervals. These location data were stored on-board within the collar on a removable Secure Digital® (SD) memory card. Johnson and Ganskopp (2008) found that collars of similar design and weight did not impede behavioral activities by elk. Collars were color coded so animals could be identified in the field and visual field observations could be linked to specific data within GPS track logs.

Figure 2.4 Color coded lightweight GPS collars sized for elk.

The 1-second GPS data collection intervals permitted very intensive spatial and temporal resolution of behavioral activity. The GPS collars continuously collected data for about 6.25 days and ran concurrently with traditional field observations after which the battery pack was completely exhausted thus limiting trial length. Expected accuracy of the GPS units was assessed during each Trial by using a static reference unit test. A dedicated GPS tracking unit was placed in an open area 2.5 meters above the ground on a wooden post adjacent to study pastures. This tracking unit remained stationary and was allowed to collect GPS location data at 1-second intervals for each trial. When averaged across all trials, logging was continuous and resulted in a mean x-y error of 1.41 m (SD = 0.83 m). Location error for the reference unit ranged from a minimum error of 0.0 m and maximum of 9.53m across all trials.

2.6 Map Development

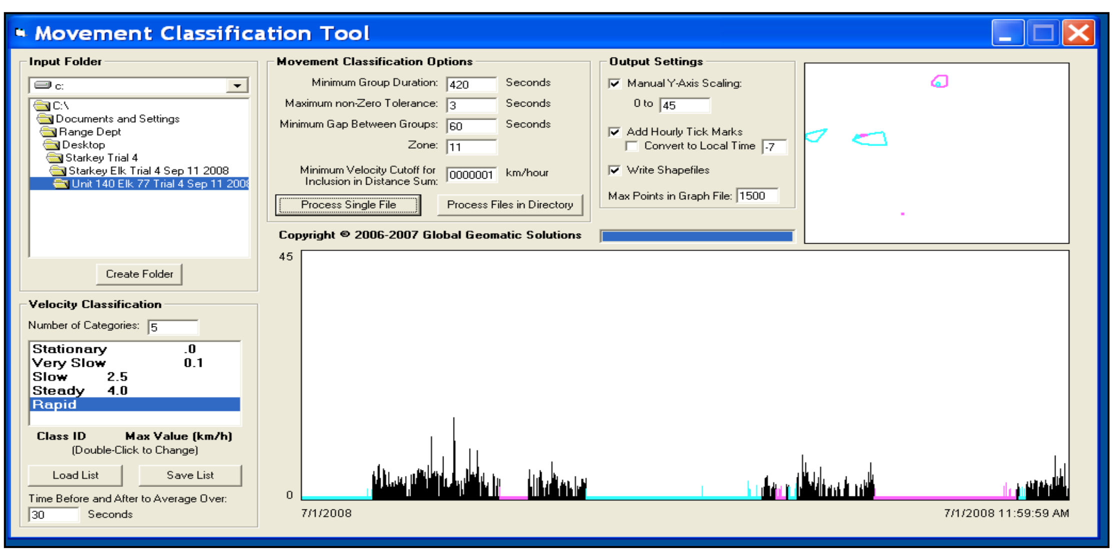
The GPS tracking collar data were retrieved from the SD memory cards as raw ASCI text with a National Marine Electronics Association (NMEA) format. These NMEA data were compiled and converted to coma –separated text files using GGS logger, a custom software executable program written by Michael Johnson (Univ. of California Santa Barbara) and placed in a Microsoft Office Excel™ worksheet. For visual display and initial data interpretation/error checking, these data were imported into the Global Mapper® v9.03® software package (Global Mapper LLC 2009) where they were illustrated as point vectors. The data was overlaid on USGS Digital Raster Graphics (DRG), Digital Elevation Models (DEM), and Digital Orthophotographic Quadrangles (DOQ) for interpretation.

2.7 Animal Movement Classification Tool

After compilation and error-checking the GPS collar data for each experimental trial were analyzed using a custom built software program called an Animal Movement Classification Tool (Johnson et al. 2009). For this analysis 345 continuous 24-hour observation periods (days) were analyzed.

The Animal Movement Classification Tool (AMCT) (Figure 2.5) classified mean GPS locations by velocity into five categories: stationary (0.0 km/hr), very slow (>0.0 to 0.1 km/hr), slow (>0.1 to 2.5 km/hr), rapid (>2.5 to 4.0 km/hr), and very rapid movement (>4.0 km/hr). These classifications were selected after field observations on elk movement. We also extracted stationary locations with duration greater than 420-seconds or 7-minutes and created shapefiles for these locations. Shapefiles of stationary locations were attributed with start date/time, end date/time, duration, and minimum convex polygon area of the stationary positions (Figure 2.6).

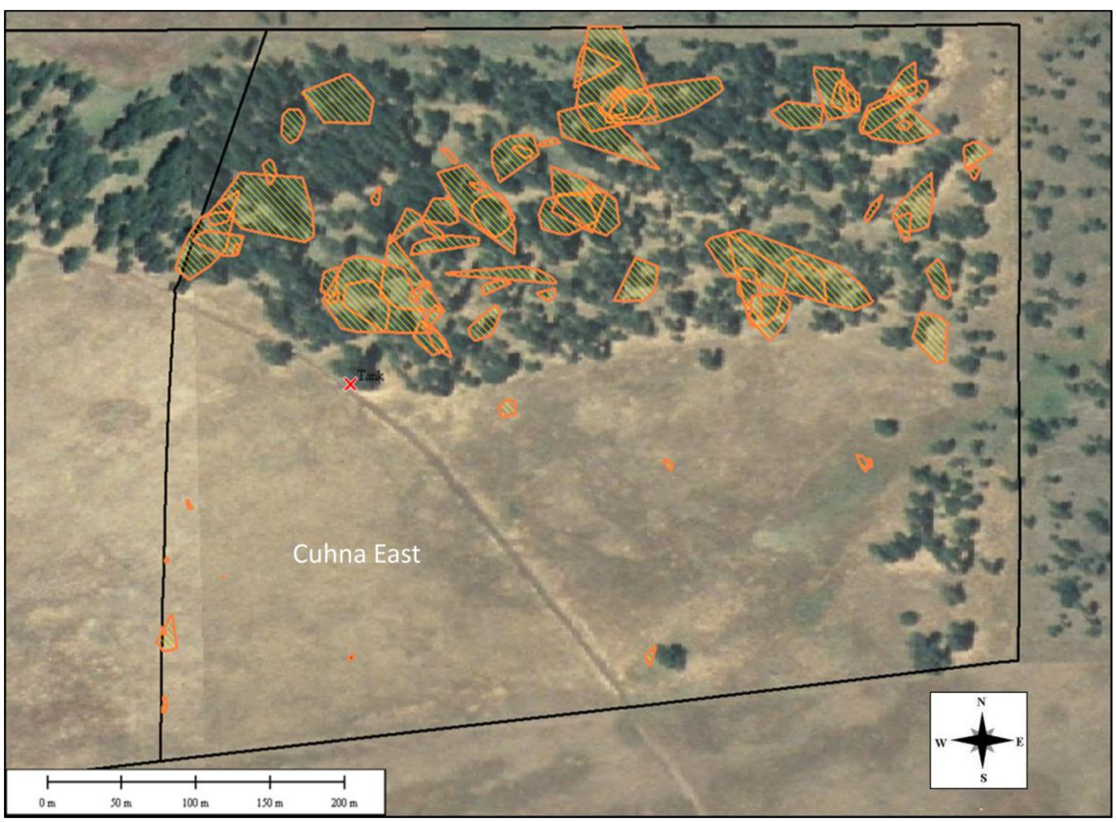
Figure 2.5 Animal Movement Classification Tool



In order to eliminate false movement from head shakes we ignored punctuated movement of less than 3-seconds in the classification of long term stationary locations. Thus a stationary period of 7 minutes could have a maximum of 3 non-zero velocities in a row. The tool was also programmed to use a running mean, averaged over 61 seconds, to attribute the original data with movement classes.

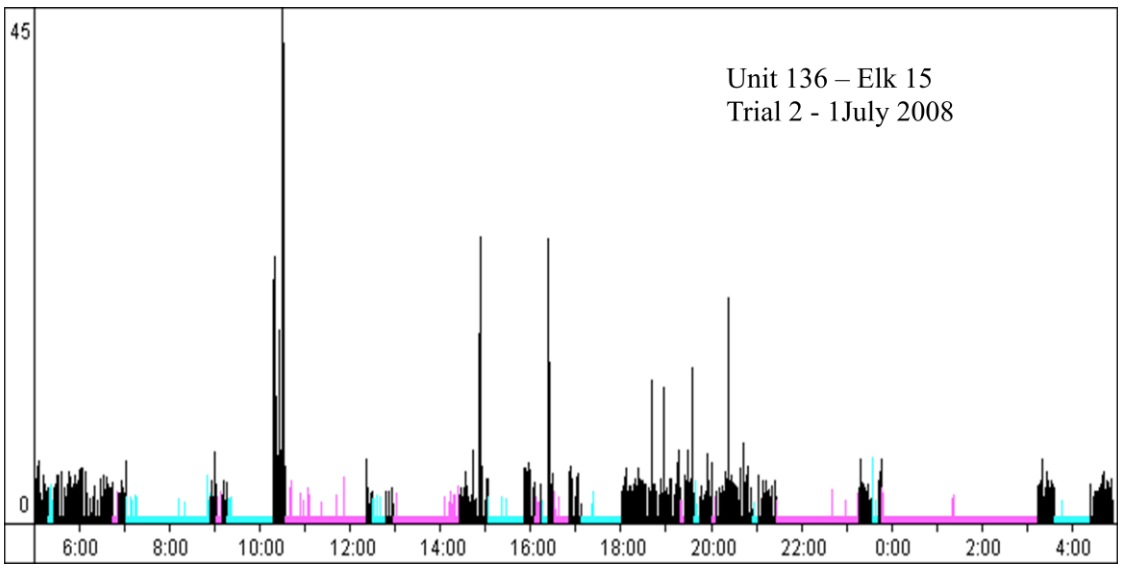
The AMCT also produced charts of velocity vs. time of day (Figure 2.7). We set Y-Axis range from 0 to 45 km/hr. Universal time was adjusted to Pacific Standard Time to be sun synchronous and uniform across all trials and hourly tic marks added.

Figure 2.6 Shape files written by the Animal Movement Classification Tool.



Stationary periods sometimes contained spikes which were probably head movements in response to insects. Activity patterns were examined in light of field notes and correlated well with grazing patterns recorded in field observation data. Speeds higher than 10 km/hr fell within the rapid or very rapid travel speeds and were recorded as short bursts (Figure 2.7).

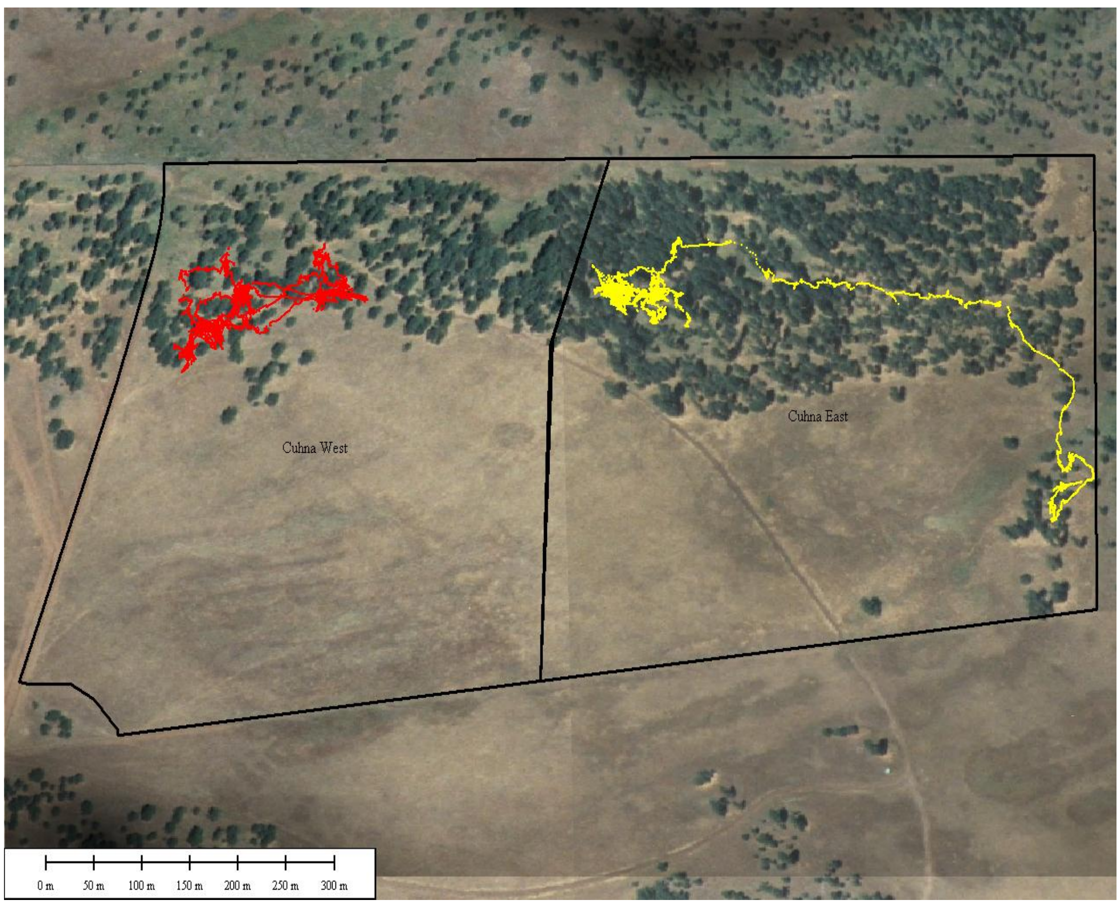
Figure 2.7 Activity patterns with velocity processed through the Animal Movement Classification Tool.



2.8 Separation of Day and Night Activity

Data processed by the Animal Movement Classification Tool was then reprocessed through another custom built software program, the Animal Nighttime Movement Classification Tool, which attributed and divided the files into day vs. night periods. We used civil twilight (when the center of the sun is 6 degrees below the horizon) as the beginning and end of the daylight period. Times for civil twilight for each Trial were obtained from the US Naval Observatory for this latitude and longitude (USNO 2009) . The day and night movement could then be compared (Figure 2.8). In Figure 2.8 data points in Cuhna West are for an animal during 1 daylight period and the points in Cuhna East are for another animal during 1 night.

Figure 2.8 Data points showing 1 nighttime and 1 daytime travel in research pastures.



2.9 Statistical analysis

Data was analyzed using a general linear model with Julian day as a covariate and moon phase and pasture (2 pastures) as factors. The covariate was employed to reduce effect of progressive seasonal change in the environment. Means were separated with Tukey's Honesty Test for differences, within the Statistical Analysis System® (SAS 2009). Julian days were utilized across all trials to control variation changes resulting from day length, temperature, phenology of plants, soil moisture, etc.

To avoid adding pseudo-travel resulting from GPS errors when an animal is stationary and overestimating movement, we eliminated all positions with no velocity from the distance calculation. Typically the 86,400 positions collected during the day would be reduced to 8 to 10 thousand. This provided a more accurate estimate of actual travel. Travel distance was also separated into daytime and nighttime periods.

Results and Discussion

Analysis of velocities of collared elk during new and full moon trials show that elk were stationary for a mean 11.54 hours (72.9% of mean total daylight hours) in new moon trials, and were stationary approximately 11.48 hours (71.5%) during full moon (Tables 2.2 and 2.3). This was not statistically significant when tested as % of time ($P = 0.901$) (daylight % of time moving new vs. full moon $P = 0.901$). In a similar fashion analysis of elk velocities during new and full moon phases at night show elk were stationary approximately 5.66 hours (68.3%) during a new moon and approximately 5.48 hours (68.5%) during a full moon again not significantly different (night % of time moving new vs. full moon $P = 0.902$) (Tables 2.2 and 2.3).

Table 2.2 Number of hours elk were stationary under a new moon during the day and night.

Trial End Date	Pasture	Julian Day	Moon Phase	% Stationary Daylight (%)	Time Stationary During Daylight Hours (hr)	% Stationary Nighttime (%)	Time Stationary During Nighttime hours (hr)
24-May-09	W	142	New	70.1	11.49	64.5	4.96
24-May-09	E	142	New	68.6	11.19	71.8	5.52
22-Jun-09	W	172	New	72.9	12.29	62.2	4.43
22-Jun-09	E	172	New	77.3	13.04	62.8	4.46
6-Jul-08	W	185	New	73.1	12.40	65.4	4.73
6-Jul-08	E	185	New	71.5	11.74	62.9	4.42
21-Jul-09	E	200	New	74.9	12.20	69.7	5.32
21-Jul-09	W	200	New	75.9	12.40	63.3	4.84
29-Sep-08	E	271	New	69.9	8.98	78.0	8.69
29-Sep-08	W	271	New	74.8	9.63	82.9	9.25
			Mean	**72.9**	**11.54**	**68.3**	**5.66**

Table 2.3 Number of hours elk were stationary under a full moon during the day and night.

Trial End Date	Pasture	Julian Day	Moon Phase	% Stationary Daylight (%)	Time Stationary During Daylight Hours (hr)	% Stationary Nighttime (%)	Time Stationary During Nighttime hours (hr)
8-Jun-09	E	157	Full	68.7	11.60	60.4	4.38
8-Jun-09	W	157	Full	68.9	11.53	60.5	4.38
21-Jun-08	W	171	Full	65.3	10.99	69.8	4.97
21-Jun-08	E	171	Full	67.7	11.41	64.8	4.61
5-Jul-09	E	185	Full	77.7	13.01	77.6	5.61
7-Jul-09	W	185	Full	77.2	12.93	70.8	5.13
20-Jul-08	W	200	Full	72.5	11.93	62.7	4.80
20-Jul-08	E	201	Full	68	11.11	67.1	5.12
16-Sep-08	E	258	Full	73.6	9.97	74.3	7.76
16-Sep-08	W	258	Full	75.8	10.32	76.5	7.99
			Mean	**71.5**	**11.48**	**68.5**	**5.48**

Rates of travel by cow elk during new moon Trials was similar (P= 0.5212) during the day (0.27 km/hr) and night (0.29 km/hr) (Table 2.4). Mean rate of travel of cow elk during the full moon Trials was also similar (P=0.9615) for both daylight (0.29 km/hr) and nighttime (0.29 km/hr) hours (Table 2.5). We compared both nighttime and daylight rate of travel by elk during new and full moon periods (Tables 2.4 and 2.5) and found no significant difference with lunar illumination (night velocity new vs. full moon P= 0.854, daylight velocity new vs. full moon P = 0.345).

Table 2.4 Mean rate of travel by elk in km/hr under a new moon during daylight and at night.

Trial End Date	Pasture	Julian day	Moon Phase	Daylight Mean Rate of Travel (km/hr)	Night Mean Rate of Travel (km/hr)
24-May-09	W	142	New	0.26	0.28
24-May-09	E	142	New	0.40	0.28
22-Jun-09	W	172	New	0.25	0.33
22-Jun-09	E	172	New	0.23	0.42
6-Jul-08	W	185	New	0.22	0.28
6-Jul-08	E	185	New	0.28	0.31
21-Jul-09	E	200	New	0.27	0.29
21-Jul-09	W	200	New	0.25	0.39
29-Sep-08	E	271	New	0.28	0.16
29-Sep-08	W	271	New	0.21	0.13
			Mean Travel (km/hr)	0.27	0.29

Table 2.5 Mean rate of travel by elk in km/hr under a full moon during daylight and at night.

Trial End Date	Pasture	Julian day	Moon Phase	Daylight Mean Rate of Travel (km/hr)	Night Mean Rate of Travel (km/hr)
8-Jun-09	W	142	Full	0.294	0.339
8-Jun-09	E	142	Full	0.333	0.459
21-Jun-08	W	172	Full	0.388	0.269
21-Jun-08	E	172	Full	0.480	0.352
5-Jul-09	W	185	Full	0.246	0.189
7-Jul-09	E	185	Full	0.249	0.230
20-Jul-08	E	200	Full	0.230	0.310
20-Jul-08	W	201	Full	0.317	0.300
16-Sep-08	E	258	Full	0.210	0.250
16-Sep-08	W	258	Full	0.192	0.228
			Mean dist. km/hr	0.29	0.29

We began our study each year during late spring and early summer when forage was abundant and lush. Temperatures were mild and soil moisture was amply available to growing forages. As the calendar year progressed, forage senesed and declined in quality, mean temperatures rose in late summer then fell in early fall, precipitation decreased and remained low, and soils in the study area dried out. Our study ended each year before there was substantial fall rains and vegetative growth. This location receives little rain in summer; most precipitation is in the form of snow. With these progressive changes through the summer and fall elk travel distances (km) tended to decrease. With these progressive climate and forage condition changes, the seasonal decrease in elk travel distance followed the linear regression formula below:

$$\hat{Y} = -0.0255JD + 11.698 \qquad R^2 = 0.4502$$

Where: $\hat{Y}$ = predicted travel distance in km, JD is Julian day. The slope of this equation was significant at ($P = 0.0012$). Daylight and nighttime travel distances also became shorter ($P = 0.001$) (Table 2.6). However, the moon phases did not significantly affect the day and night time daily travel distances ($P = 0.234$).

Table 2.6 Full day and nighttime travel distance of elk in kilometers.

Pasture	Trial End Date	Julian Day	Moon Phase	24-hour Travel Distance (km)	Night Travel Distance (km)	Daylight Travel Distance (km)
W	24-May-09	142	New	6.46	2.18	4.28
E	24-May-09	142	New	8.71	2.12	6.59
E	8-Jun-09	157	Full	7.41	2.46	4.95
W	8-Jun-09	157	Full	8.9	3.32	5.58
W	21-Jun-08	171	Full	8.41	1.91	6.50
E	21-Jun-08	171	Full	10.6	2.51	8.09
W	22-Jun-09	172	New	6.63	2.36	4.27
E	22-Jun-09	172	New	6.82	2.98	3.84
E	5-Jul-09	185	Full	5.49	1.37	4.12
W	7-Jul-09	185	Full	5.82	1.66	4.16
W	6-Jul-08	185	New	5.71	2.01	3.70
E	6-Jul-08	185	New	6.78	2.24	4.54
E	21-Jul-09	200	New	6.62	2.19	4.43
W	21-Jul-09	200	New	7.02	3.00	4.02
W	20-Jul-08	200	Full	6.16	2.37	3.79
E	20-Jul-08	201	Full	7.46	2.29	5.17
E	16-Sep-08	258	Full	5.45	2.61	2.84
W	16-Sep-08	258	Full	4.99	2.38	2.61
E	29-Sep-08	271	New	5.42	1.82	3.60
W	29-Sep-08	271	New	4.17	1.42	2.75

Examination of velocity diagrams indicate elk typically forage between 7 and 11 periods per day. Normal grazing periods typically occur over short time frames lasting between 15 to 30 minutes in duration. Longer grazing events occur in the morning between 0330 to about 0530, 0700 to about 0830 and again in the early evening from about 1700 to 2100 hours. These longer grazing events can last from 1 to 4 hours in duration. See appendix Figures 1-10 showing representative velocity patterns of cow elk.

Examination of stationary periods from each trial indicates elk spend more time in open space during the late spring and early summer and are less tied to tree canopy. The coble strewn surfaces of the meadows contain biscuit areas (raised soil islands) which provide better forage, softer bedding, and cover. As vegetation becomes less palatable and temperature climbs the elk congregate more under tree canopy. They favor sites near seep areas or water, and in lush vegetation as can be seen in Appendix Figures 11-20.

The length of stationary periods of cow elk (including rumination) across all trials was sorted by duration in an effort to characterize diurnal activity. There were 7,479 identified periods when elk were stationary for more than 7 minutes. The mean duration of all stationary events was 0.83 hr (sd = 0.89 hr). The longest stationary event was 6.94 hr and only 6 lasted longer than 6 hours (Figure 2.9). Most stationary events were less than 1 hr duration (x =5099). Across all Trials, 873 stationary events were longer than 2 hours and 194 were longer than 3 hours.

Figure 2.9 Length of stationary periods of cow elk across all trials sorted by duration. There were 7479 identified stationary periods when elk were stationary for more than 7 minutes (mean 0.83 hr, standard deviation = 0.89 hr). The longest stationary period was 6.94 hr but only 6 were recorded longer than 6 hrs. Most stationary periods were less than 1 hr (5099).

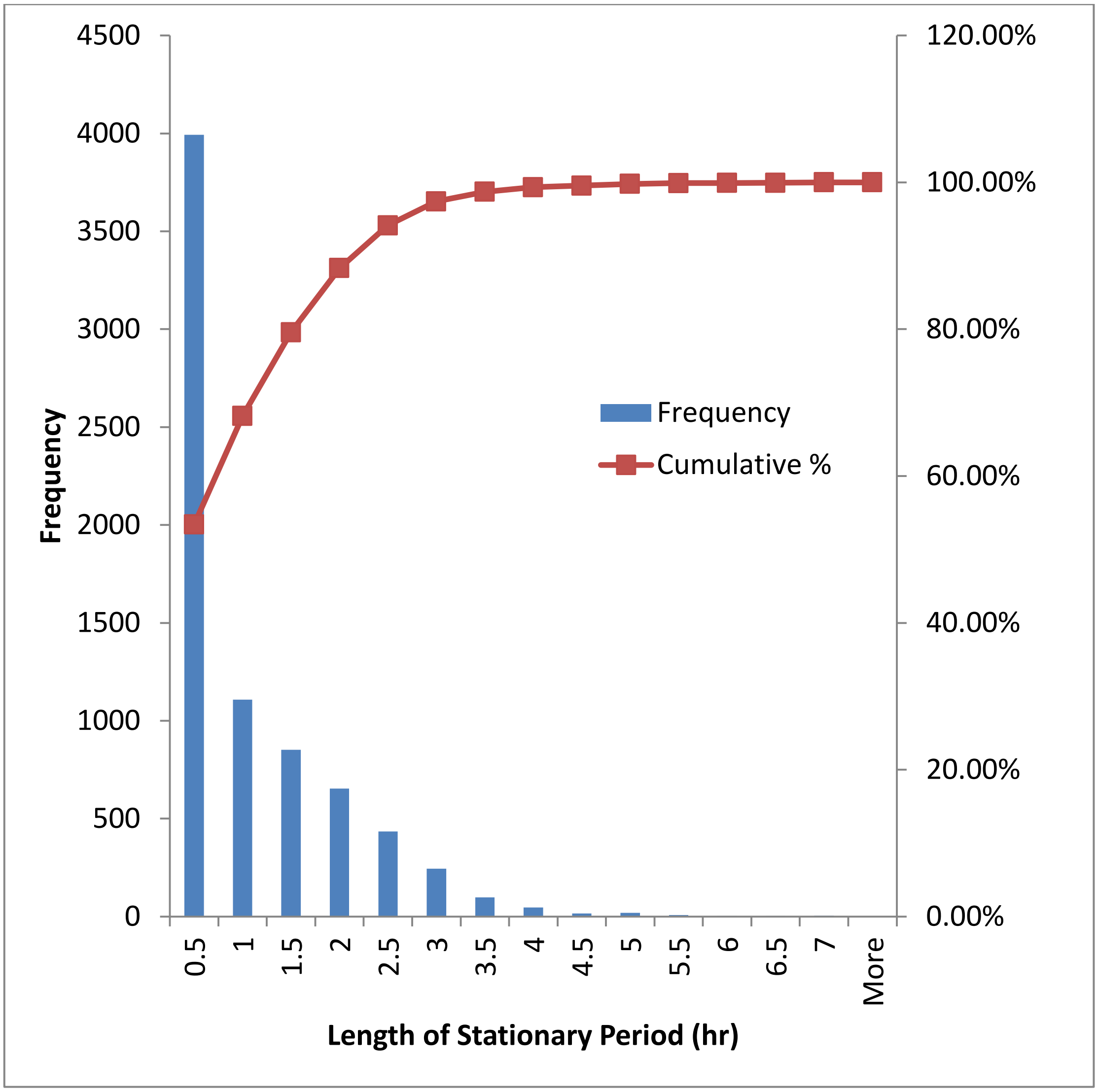
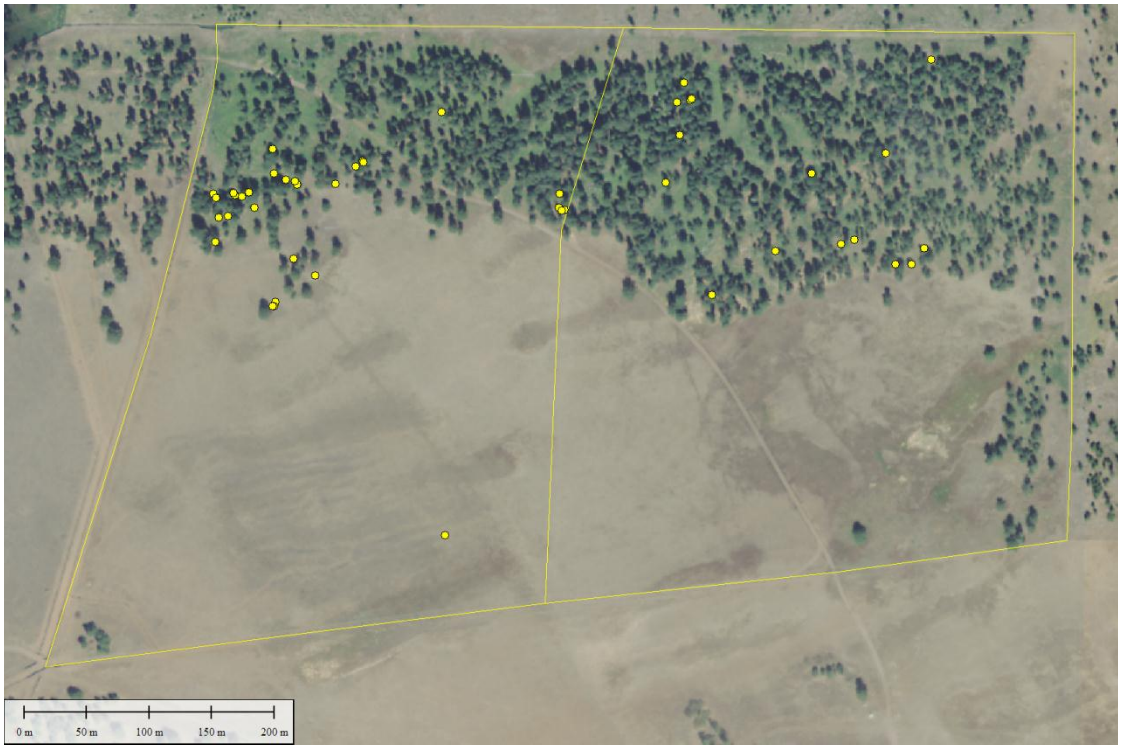


Figure 2.10 Location of stationary events longer than 4 hours across all Trials. Most of the 50 locations recorded are in timber.



Conclusions

It is a common popular belief that Rocky Mountain Elk are strongly influenced by moon phase and illumination which is dependent on the Earth's rotation (Aschoff 1966). Changes including lengths of day, hormonal phases of yearly cycle and biological development are all connected to these rhythms. However, in this study elk activity budget or travel distance responses were not significantly altered based on lunar phases.

Under both new and full moons, elk exhibited similar rates of travel between daylight and nighttime hours. Elk travel distance was also similar between moon phases and mean travel across all trials was 6.75 km/day.

Daytime and nighttime activity decreased as the calendar year increased. Trials for this study were conducted during the late spring through summer into early fall, when temperature variation, vegetative growth, and lengths of day change due to seasonality. Increasing temperatures and decreasing precipitation affected vegetative growth, and activity budgets of the elk, therefore seasonality played a larger role affecting elk movement patterns than moon phase.

Acknowledgements

The authors would like to thank Mr. Michael D. Johnson, for his contributions throughout the length of the study creating algorithms utilized to process data collected. We would also like to thank Mr. Conrad Ndzeidze for his contribution in creating an algorithm which could separate day from night utilizing civil twilight, and Dr. Dave Thomas for his help with statistical analysis.

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Chapter 3

SUMMARY AND CONCLUSIONS

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SUMMARY AND CONCLUSIONS

Rocky Mountain Elk (*Cervus elaphus nelsoni*) range from the Canadian Northwest Territory to New Mexico along the Rocky Mountain Ranges and from the Coastal and Cascade Mountains of Oregon and Washington State, to the Sierra Nevada Mountains in Northern California (RMEF 1999). There are also a few small pockets of elk populations located in Michigan, Pennsylvania, Southeastern Kentucky, Eastern Oklahoma, Central Florida, and South Western Texas (Bryant and Maser 1982) (Wichrowski et al. 2005).

Ecologists study elk behavioral patterns to better understand their movement across landscape. Monitoring elk and other wildlife is important especially for reintroduced species, but also for predation risk and social interactions (Wichrowski et al. 2005) (Forester et al. 2007).

Elk moving across landscape are diurnal and use circadian rhythm to manage activity budgets. Circadian rhythm is a type of cycle that governs the biological clock over 24 - hour periods (Aschoff 1965). Humans and elk share this type of biological fine tuning which is connected to lengths of day and night or chronobiology, and has been around since pre-history (wordiQ.com 2010). Elk also see keenly at night and can move easily across landscape because of a reflective eye structure called tapetum, positioning and type of rods and cones within the eye, and the shape of the cornea which allows more light to enter the eye (Samuelson 2010).

The objectives of our study were to quantify the circadian characteristics and spatial/temporal behavior of Rocky Mountain Elk (*Cervus elaphus nelsoni*) as detected by high frequency 1-second GPS logging technologies during periods with and without moonlight. This study characterized elk travel activity budgets during full and new moon phases, to determine if elk travel more during the day after a new moon or full moon, to determine if the phase of the moon affects full day travel distance of an elk, and to determine if the phase of the moon effects elk activity patterns.

The study area was located 35 km west of LaGrande, Oregon, USA, at the Starkey Experimental Forest and Range (Lat. 45°.10’-18”N, Long. 118°.28’-37”W) and consisted of two fenced pastures: Cuhna West (16.6 ha) and Cuhna East (17.1 ha) (USDA/USFS 2003). The landscape contained dry mountain meadows and niche forests of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Ponderosa pine (*Pinus ponderosa* C. Lawson) at an elevation of 1220 m. (4000 ft.) with a semiarid continental climate.

Ten mature, non-lactating, non-pregnant cow elk were used in this study. These elk were selected from a research herd of more than 60 cow elk at the U.S. Forest Service Starkey Experimental Forest and Range (Wisdom et.al. 1993). The elk were hand-reared by technicians on 3,600 acres of research area enclosures allowing for free range similar to wild distributions with limited public access (USDA/USFS 1989) (1993 Wisdom et al). Each animal was named, ear-tagged, and numbered when undergoing intensive training (neonate-human bonding, halter leading, trailer transport) by Starkey technicians for nutrition studies. At the time of our study these elk were 17 years old, and weighed between 204 kg and 354 kg (450 and 780 lbs). These animals eventually became less friendly or accepting of human interaction (more similar to wild) and thus became good candidates for this study. Handling and installation of elk GPS collars was conducted by the USFS personnel following standard protocols defined by their Institutional Animal Care and Use Committee (Wisdom et.al. 1993).

The movements of the ten cow elk were monitored at1-second intervals using GPS data logging collars. These collars weighed 0.9 kg and recorded the following parameter values for each GPS location: latitude, longitude, Universal date and time (GMT), velocity, number of satellites used to obtain the GPS fix, and fix quality at 1-second intervals. These location data were stored on-board within the collar on a removable Secure Digital® (SD) memory card. Johnson and Ganskopp (2008) found that collars of similar design and weight did not impede behavioral activities by elk. Collars were color coded so animals could be identified in the field and visual field observations could be linked to specific data within GPS track logs.

The 1-second GPS data collection intervals permitted very intensive spatial and temporal resolution of behavioral activity. The GPS collars continuously collected data for about 6.25 days and ran concurrently with traditional field observations after which the battery pack was completely exhausted limiting trial length. Expected accuracy of the GPS units was assessed during each Trial by using a static reference unit test. A dedicated GPS tracking unit was placed in an open area 2.5 meters above the ground on a wooden post adjacent to study pastures. This tracking unit remained stationary and was allowed to collect GPS location data at 1-second intervals for each trial.

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Human field observations were collected concurrently with GPS data at twice monthly intervals during 2008 and 2009. Focal animal sampling methods described by Nelson and Leege (1982) were used in our study. Data was collected on a form developed by Dr. David Ganskopp which permitted minute by minute observations of elk in the field, and recorded: foraging, bedding, walking, standing, grooming, and drinking (Ganskopp and Vavra 1987). Local weather and other events of interest were also recorded on field data sheets during observation of elk.

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Rates of travel by cow elk during new moon Trials was similar (P= 0.5212) during the day (0.27 km/hr) and night (0.29 km/hr). Mean rate of travel of cow elk during the full moon Trials was also similar (P=0.9615) for both daylight (0.29 km/hr) and nighttime (0.29 km/hr) hours. We compared both nighttime and daylight rate of travel by elk during new and full moon periods and found no significant difference with lunar illumination (night velocity new vs. full moon P= 0.854, daylight velocity new vs. full moon P = 0.345).

We began our study each year during late spring and early summer when forage was abundant and lush. Temperatures were mild and soil moisture was amply available to growing forages. As the calendar year progressed, forage senesed and declined in quality, mean temperatures rose in late summer then fell in early fall, precipitation decreased and remained low, and soils in the study area dried out. Our study ended each year before there was substantial fall rains and vegetative growth. This location receives little rain in summer; most precipitation is in the form of snow. With these progressive changes through the summer and fall elk travel distances (km) tended to decrease. With these progressive climate and forage condition changes, the seasonal decrease in elk travel distance followed the linear regression formula below:

$$\hat{Y} = -0.0255JD + 11.698 \qquad R^2 = 0.4502$$

Where: $\hat{Y}$ = predicted travel distance in km, JD is Julian day. The slope of this equation was significant at (P = 0.0012). Daylight and nighttime travel distances also became shorter (P = 0.001). However, the moon phases did not significantly affect the day and night time daily travel distances (P = 0.234).

Examination of velocity diagrams indicate elk typically forage between 7 and 11 periods per day. Normal grazing periods typically occur over short time frames lasting between 15 to 30 minutes in duration. Longer grazing events occur in the morning between 0330 to about 0530, 0700 to about 0830 and again in the early evening from about 1700 to 2100 hours. These longer grazing events can last from 1 to 4 hours in duration.

Examination of stationary periods from each trial indicates elk spend more time in open space during the late spring and early summer and are less tied to tree canopy. The coble strewn surfaces of the meadows contain biscuit areas (raised soil islands) which provide better forage, softer bedding, and cover. As vegetation becomes less palatable and temperature climbs the elk congregate more under tree canopy. They favor sites near seep areas or water, and in lush vegetation.

The length of stationary periods of cow elk across all trials was sorted by duration in an effort to characterize diurnal activity. There were 7,479 identified periods when elk were stationary for more than 7 minutes. The mean duration of all stationary events was 0.83 hr (SD = 0.89 hr). The longest stationary event was 6.94 hr and only 6 lasted longer than 6 hrs. Most stationary events were less than 1 hr duration (x =5099). Across all Trials, 873 stationary events were longer that 2 hrs and 194 were longer than 3 hrs.

In conclusion it is a common popular belief that Rocky Mountain Elk are strongly influenced by moon phase and illumination which is dependent on the Earth's rotation (Aschoff 1966). Changes including lengths of day, hormonal phases of yearly cycle, and biological development are all connected to these rhythms. However, in this study elk activity budget or travel distance responses were not significantly altered based on lunar phases.

Under both new and full moons, elk exhibited similar rates of travel between daylight and nighttime hours. Elk travel distance was also similar between moon phases and mean travel across all trials was 6.75 km/day.

Daytime and nighttime activity decreased as the calendar year increased. Trials for this study were conducted during the late spring through summer into early fall, when temperature variation, vegetative growth, and lengths of day change due to seasonality. Increasing temperatures and decreasing precipitation affected vegetative growth, and activity budgets of the elk, therefore seasonality played a larger role affecting elk movement patterns than moon phase.

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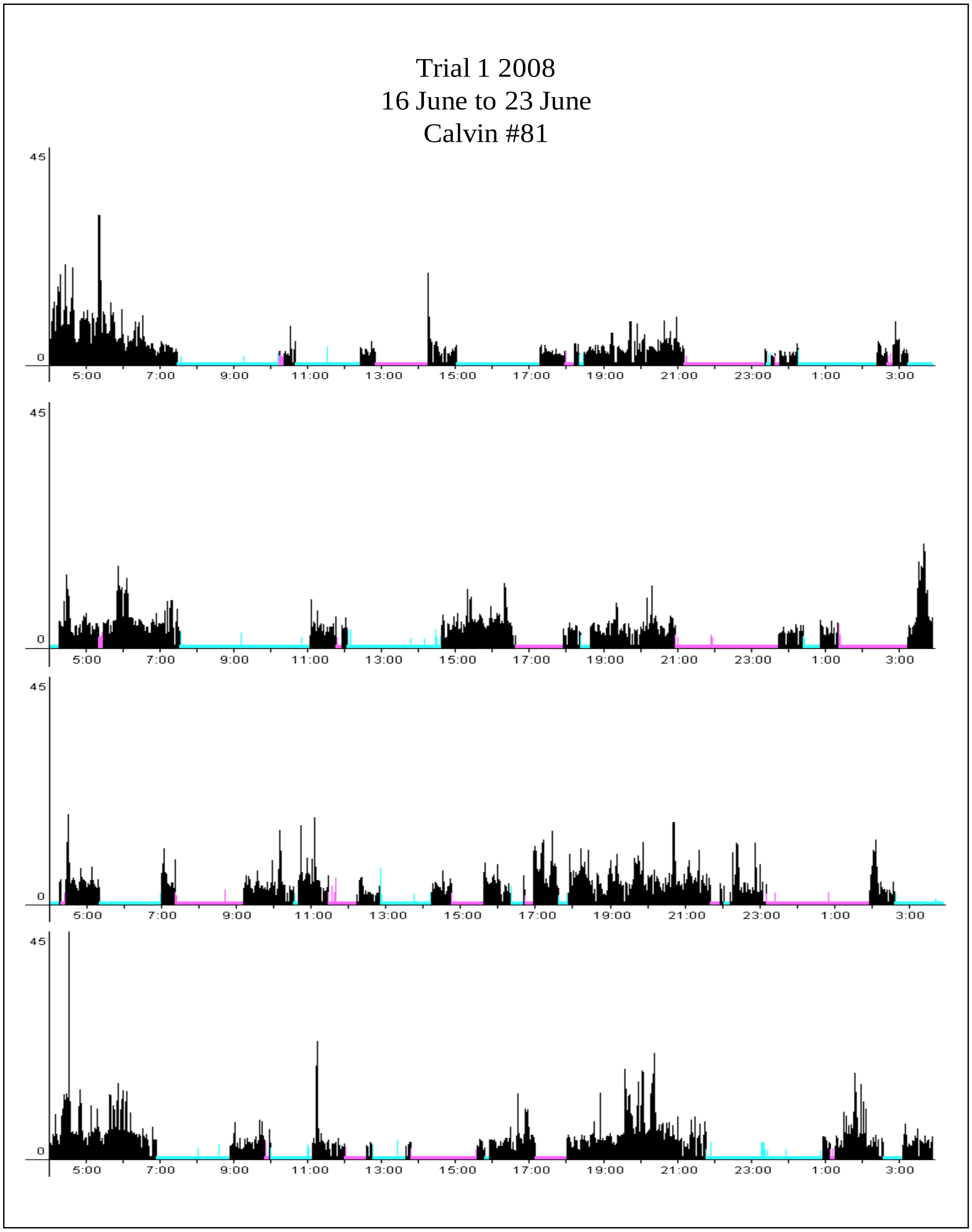
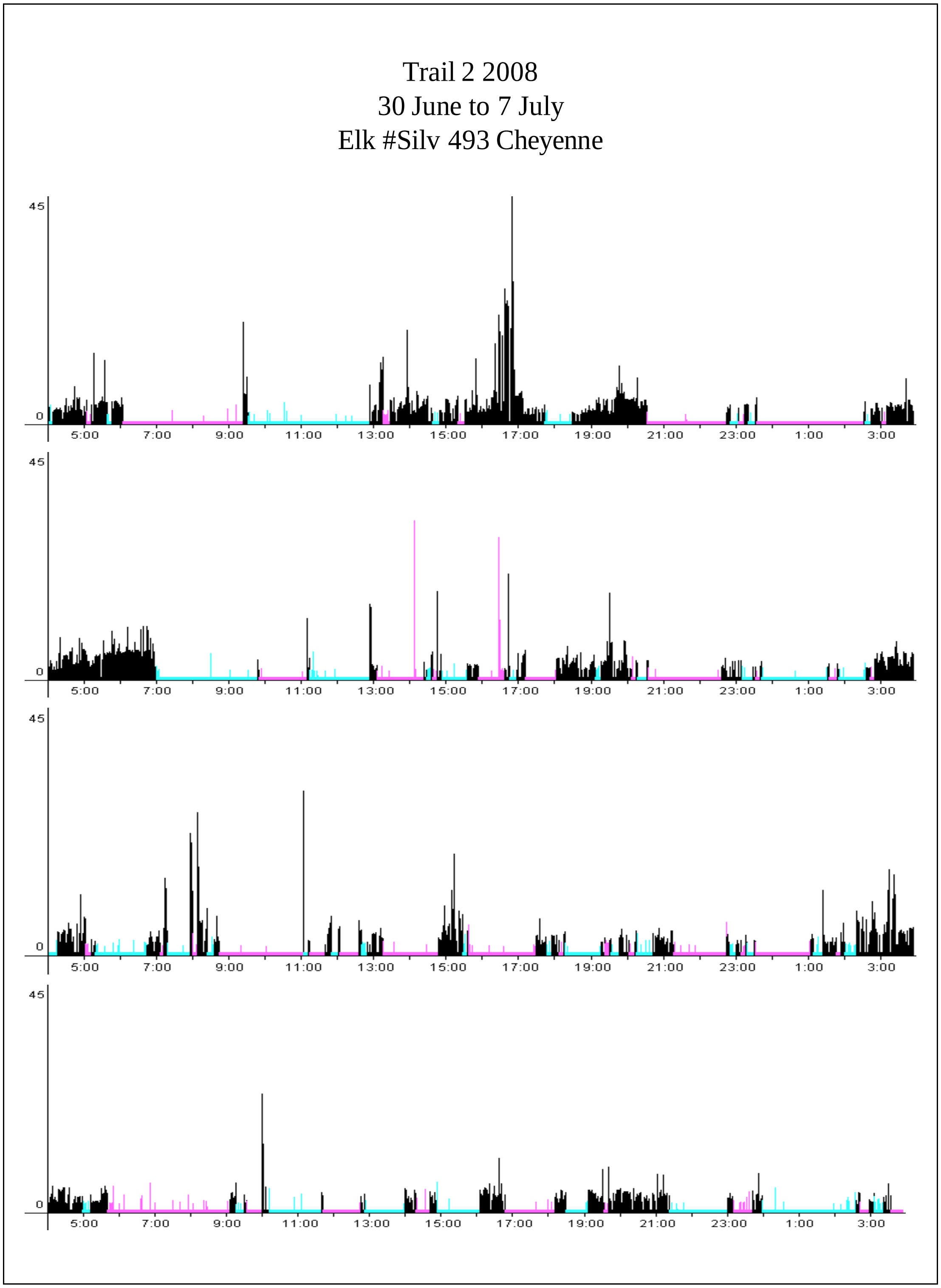
APPENDIX

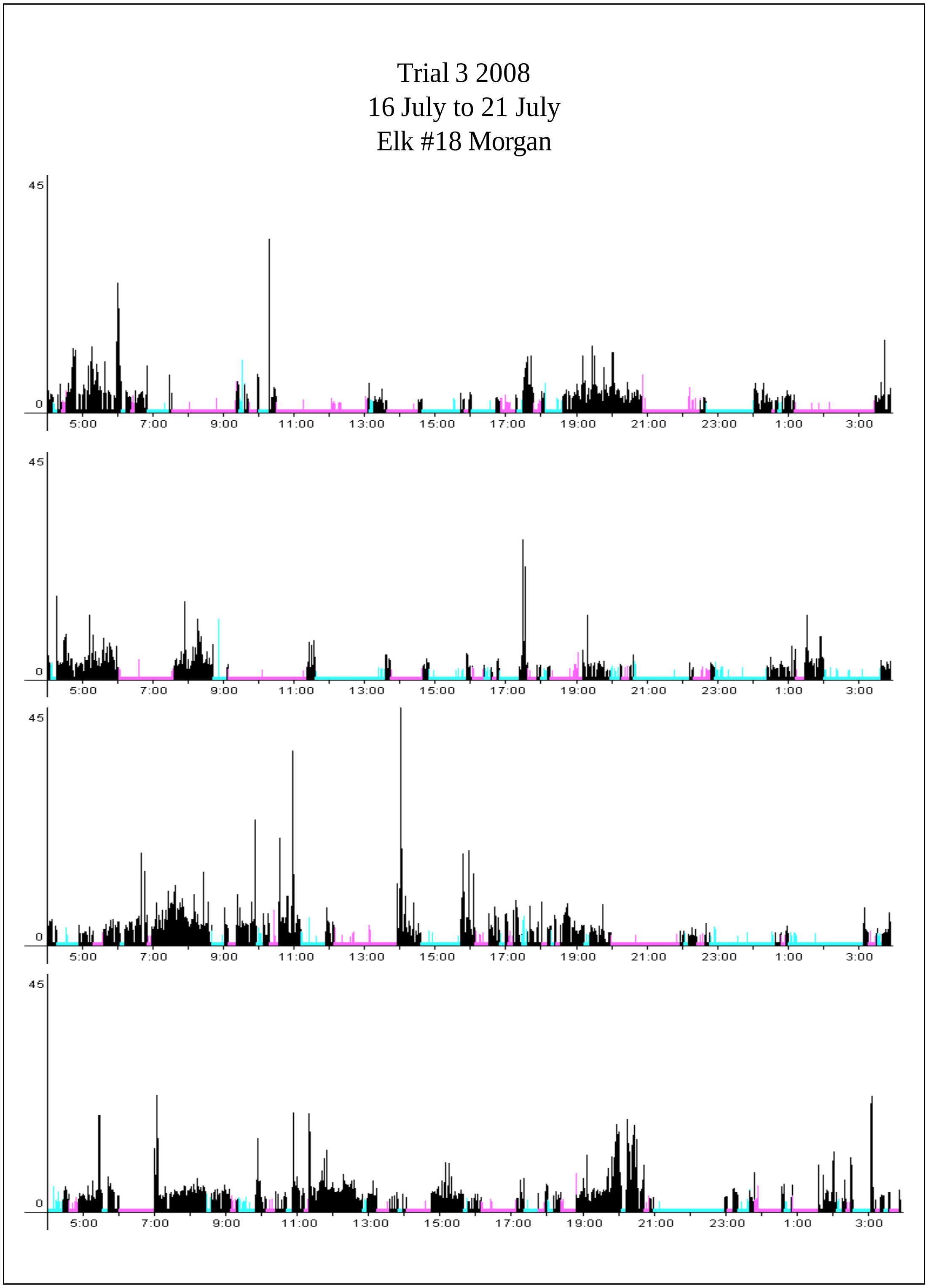
APPENDIX FIGURE 1. Representative Velocity Patterns of Cow Elk Trial 1 - 2008



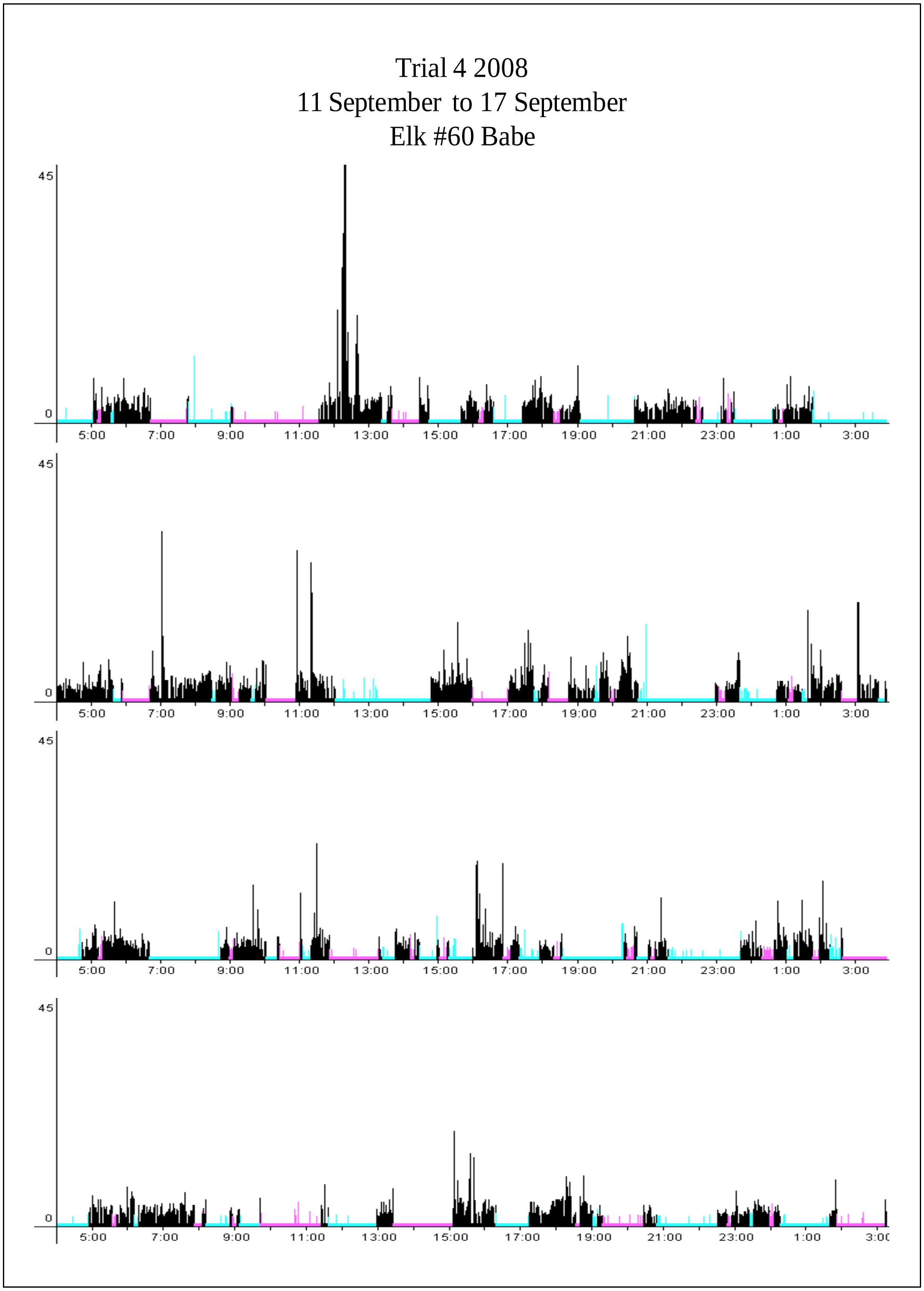
APPENDIX FIGURE 2. Representative Velocity Patterns of Cow Elk Trial 2 - 2008



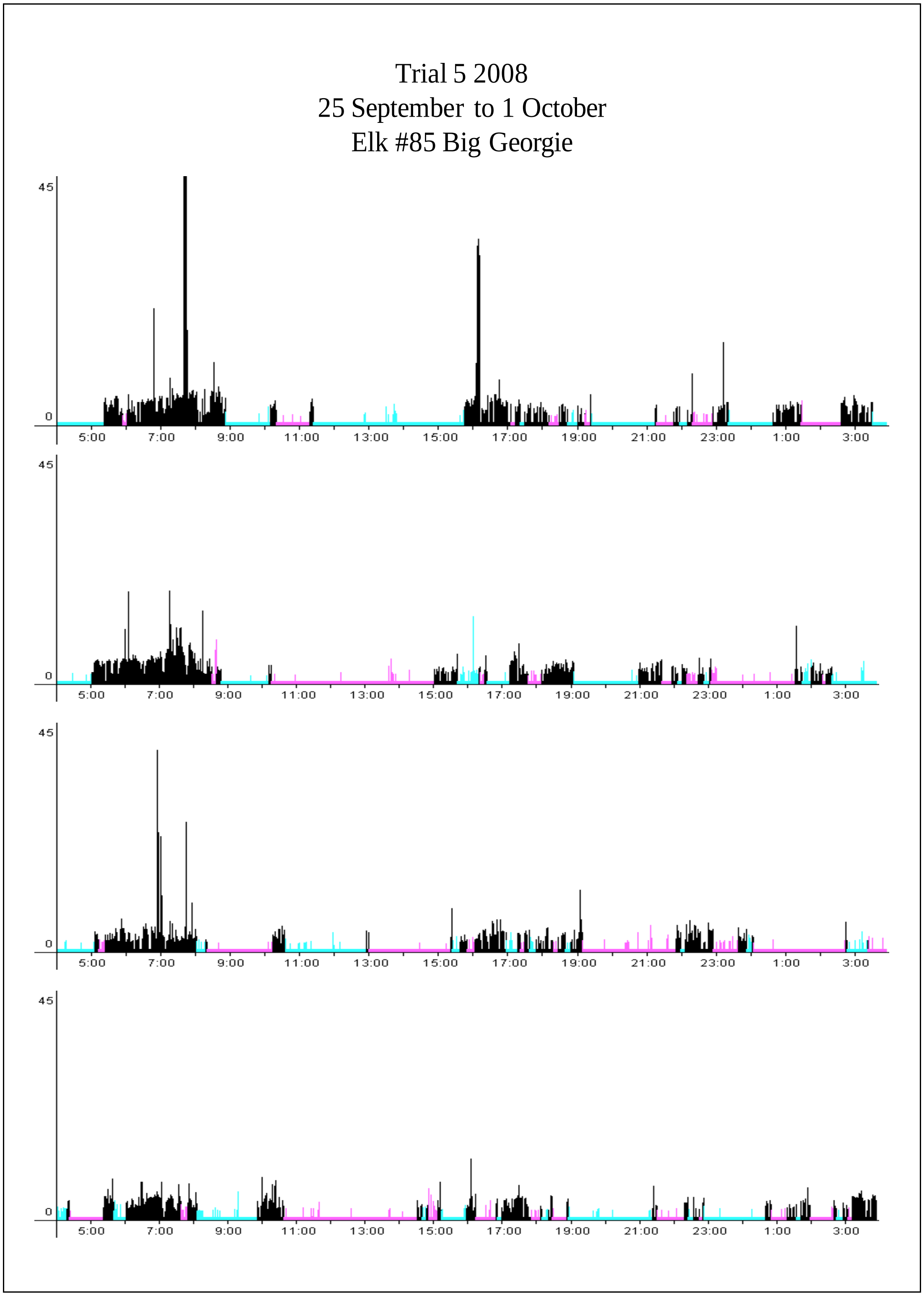
APPENDIX FIGURE 3. Representative Velocity Patterns of Cow Elk Trial 3 - 2008



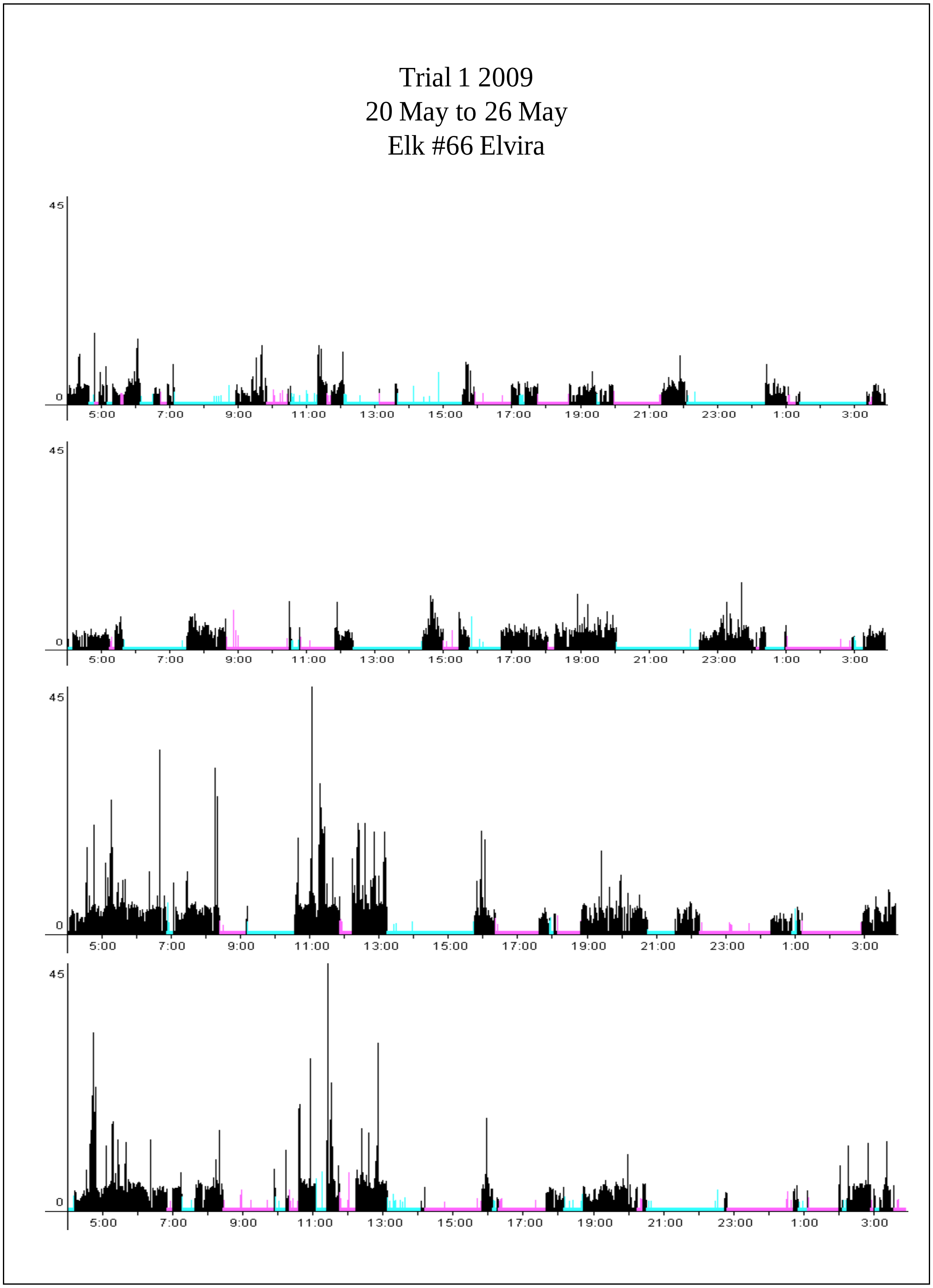
APPENDIX FIGURE 4. Representative Velocity Patterns of Cow Elk Trial 4 – 2008



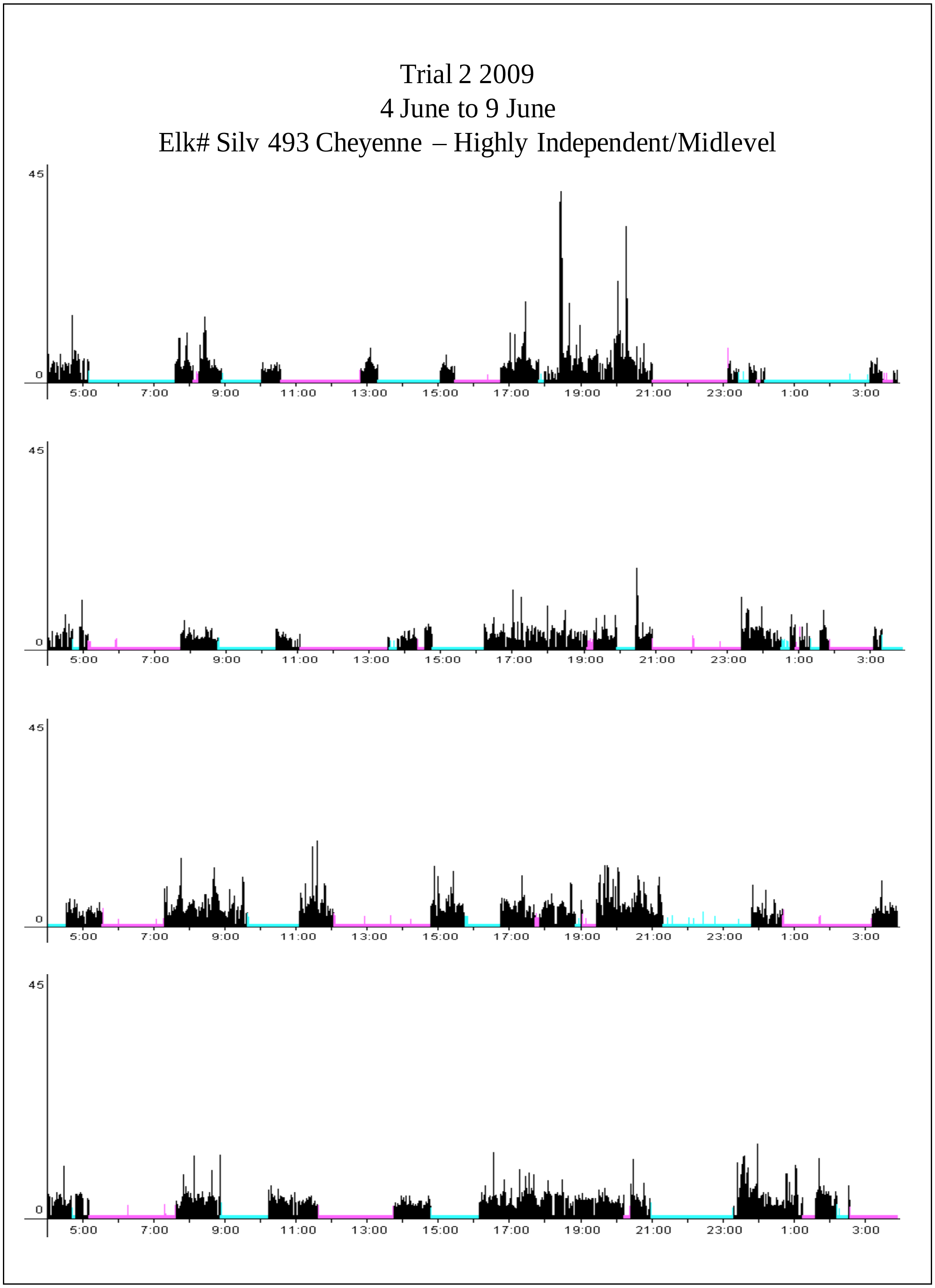
APPENDIX FIGURE 5. Representative Velocity Patterns of Cow Elk Trial 5 - 2008



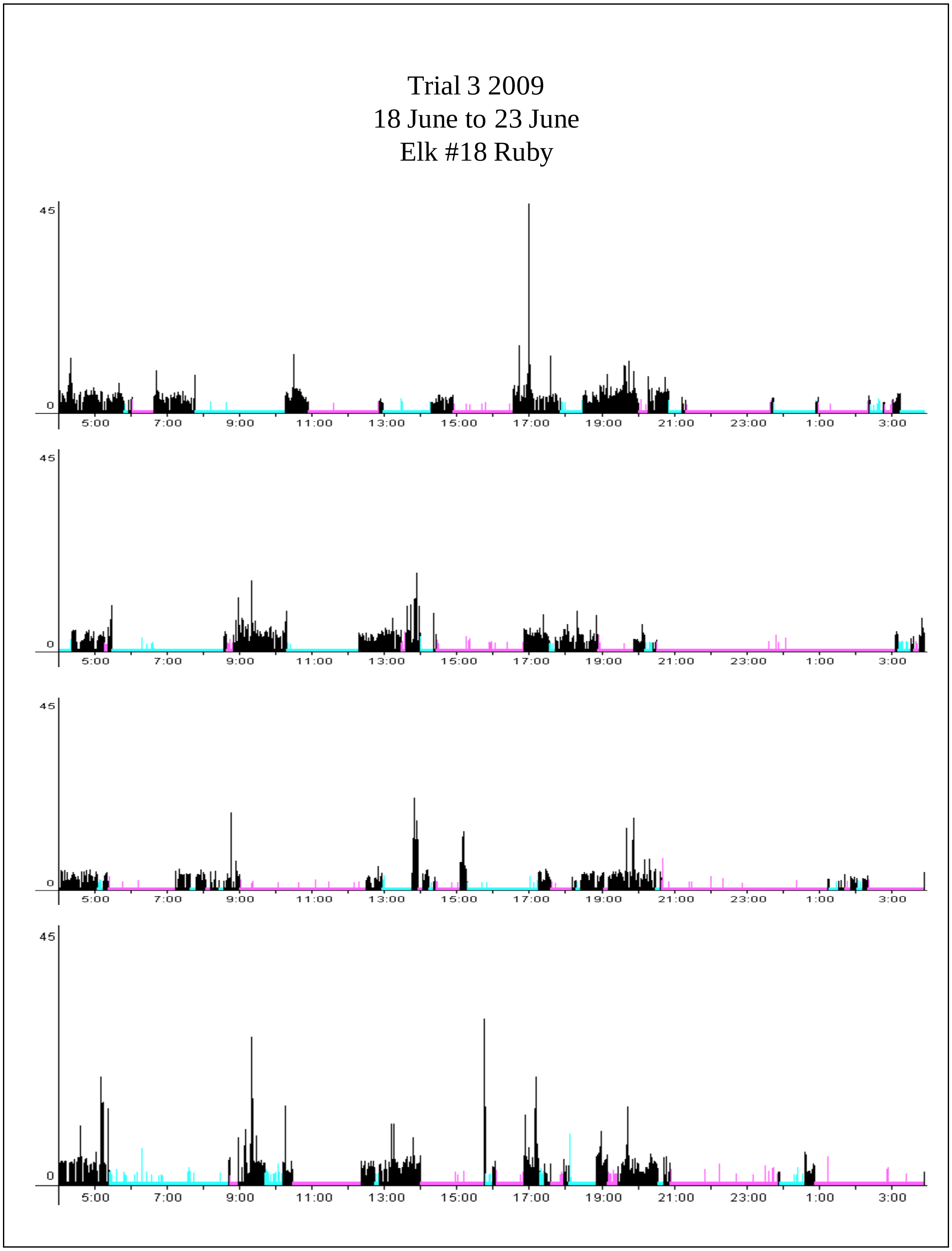
APPENDIX FIGURE 6. Representative Velocity Patterns of Cow Elk Trial 1 – 2009



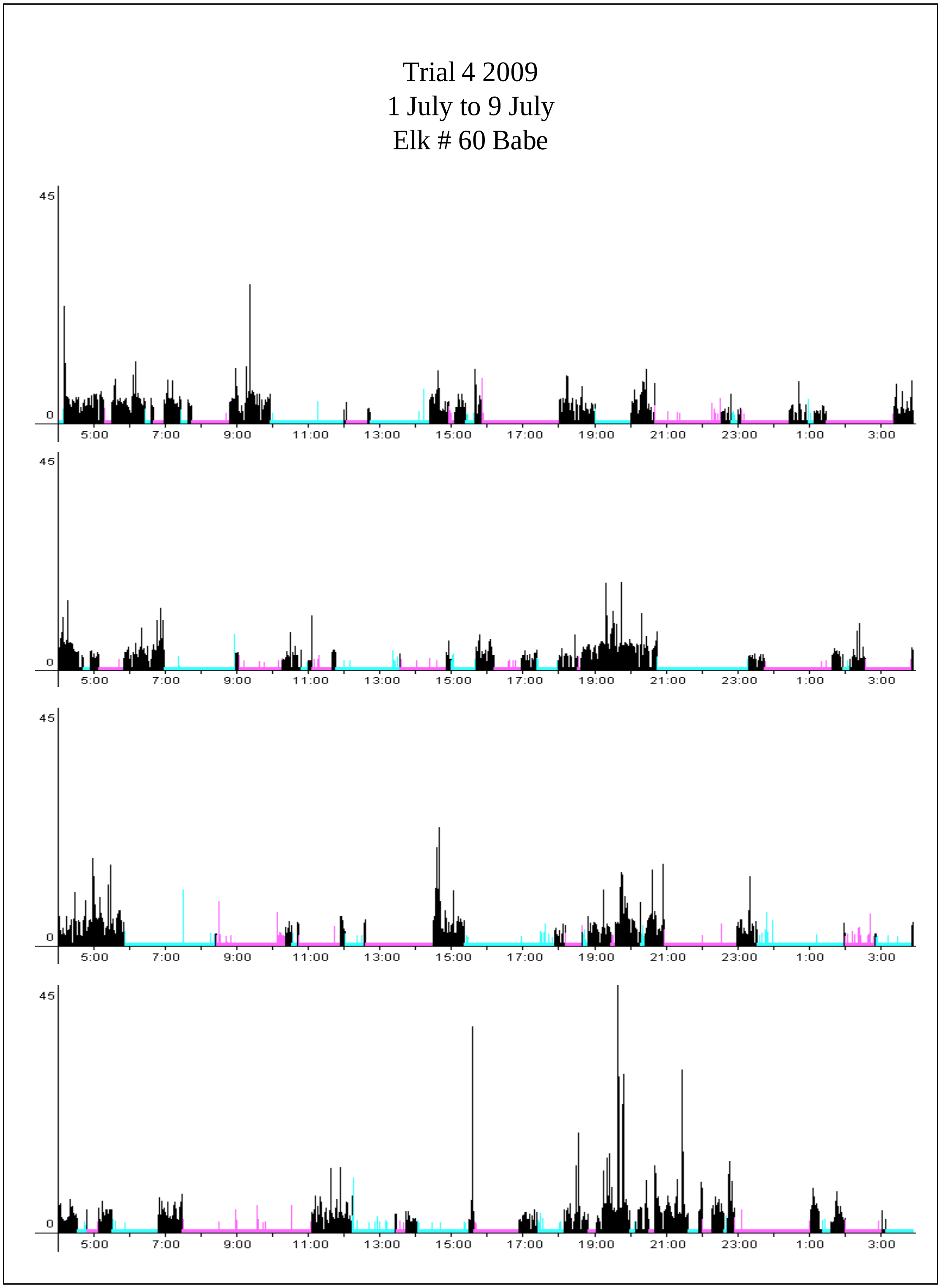
APPENDIX FIGURE 7. Representative Velocity Patterns of Cow Elk Trial 2 - 2009



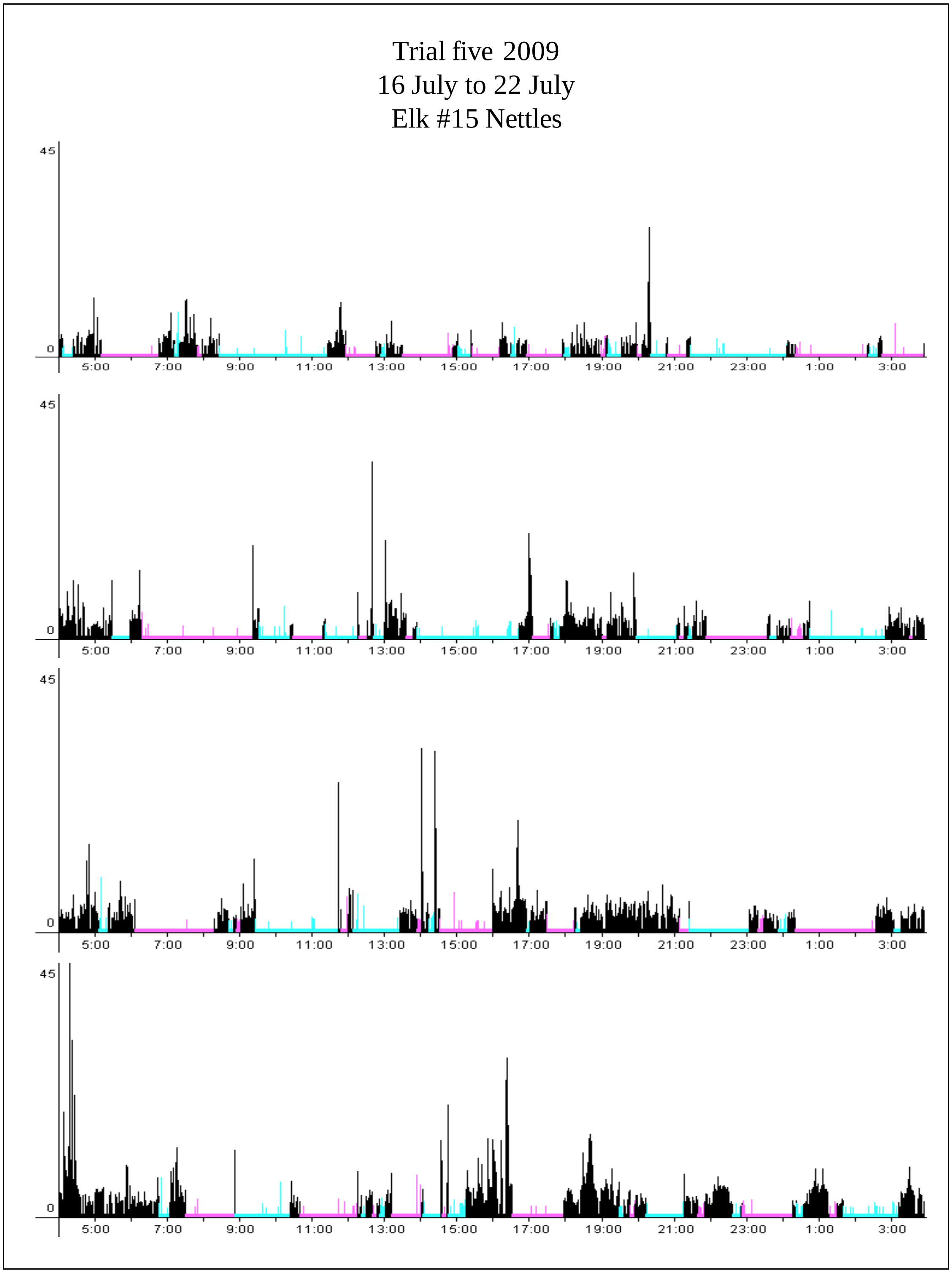
APPENDIX FIGURE 8. Representative Velocity Patterns of Cow Elk Trial 3 - 2009



APPENDIX FIGURE 9. Representative Velocity Patterns of Cow Elk Trial 4 - 2009



APPENDIX FIGURE 10. Representative Velocity Patterns of Cow Elk Trial 5 – 2009



APPENDIX FIGURE 11. Stationary Positions Trial 1 2008

APPENDIX FIGURE 12. Stationary Positions Trial 2 2008

APPENDIX FIGURE 13. Stationary Positions Trial 3 2008

APPENDIX FIGURE 14. Stationary Positions Trial 4 2008

APPENDIX FIGURE 15. Stationary Positions Trial 5 2008

APPENDIX FIGURE 16. Stationary Positions Trial 1 2009

APPENDIX FIGURE 17. Stationary Positions Trial 2 2009

APENDIX FIGURE 18. Stationary Positions Trial 3 2009

APPENDIX FIGURE 19. Stationary Positions Trial 4 2009

APPENDIX FIGURE 20. Stationary Positions Trial 5 2009