MOVEMENTS AND HABITAT USE OF FEMALE ROOSEVELT ELK IN RELATION TO HUMAN DISTURBANCE ON THE HOKO AND DICKEY GAME MANAGEMENT UNITS, WASHINGTON

by

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ABSTRACT

Movements and Habitat Use of Female Roosevelt Elk in Relation to Human Disturbance on the Hoko and Dickey Game Management Units, Washington

Jason T Storlie

Anthropogenic disturbance may alter the movements and habitat use of Roosevelt elk (*Cervus elaphus roosevelti*). Persistent human disturbance may ultimately lead to increased energetic demands, decreased reproductive success, a greater risk of predation, and the avoidance of habitats that would otherwise be utilized. Home range size, habitat use, movements, and herd fidelity were measured on 14 radio-collared female elk to assess the effect of logging and hunting disturbances on the Hoko and Dickey Game Management Units, Clallam County, Washington.

Mean home range size was 41 ± 8 km^2 ($\bar{x} \pm$ *SE;* minimum convex polygon), 43 ± 8 km^2 (95% fixed kernel), and 6 ± 1 km^2 (50% fixed kernel). The mean concentrated use area (50% fixed kernel) size was 4 ± 1 km^2 prior to the hunting season and was significantly smaller than the estimate of 8 ± 2 km^2 during the hunting season ($P < 0.01$).

Distances of elk from logging activities during the day significantly exceeded night distances ($P < 0.01$). Day-time distances to main travel routs throughout the study area were also significantly greater than night distances during the hunting season ($P < 0.01$). Mean daily movements were greatest during the fall and least during the calving season ($P < 0.01$). Mean daily movements were also significantly greater during the hunting season than prior to the hunting season ($P < 0.01$).

Habitats associated with permanent sources of water, and timber seral stage 0 – 9 years were consistently used more than expected ($P < 0.01$). Conversely, timber seral stage > 21 years was used less than expected across all seasons ($P < 0.01$), except during the hunting season when it was used equal to availability. Elk also used distances within 50 m of water more than expected ($P < 0.01$) and distances exceeding 400 m less than expected ($P < 0.01$).

During the hunting season, distances exceeding 400 m from primary roads were used more than expected ($P < 0.01$), and distances within 200 m were used less than expected ($P < 0.01$). Elk used distances within 100 m of secondary roads less than expected across all seasons ($P < 0.01$). During the hunting season, distances exceeding 600 m from paved roads were used more than expected ($P < 0.01$), and distances within 600 m were used less than expected ($P < 0.01$).

Movements and habitat use by female elk were modified by sources of anthropogenic disturbance during this study. The long-term consequences of even-aged stand management may be minimized by implementing silvicultural alternatives such as patch-cuts (i.e. < 5 acres) or uneven-aged timber management coupled with commercial thinning. Such changes may improve or create a greater interspersion of forage and cover for elk. The periodic closure of public-use roads, especially during the hunting season, may reduce sources of human disturbance. Maintaining the closure of all other roads that have traditionally prohibited the use of public-use vehicles will most likely contribute to the productivity of elk on the study area.

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This thesis is dedicated in loving memory to my father (Alvin Storlie) and grandmother (Jean Fox) who both lost their courageous battles with cancer during the preparation of this manuscript. Life is to be enjoyed, not endured!

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INTRODUCTION

Roosevelt elk (*Cervus elaphus roosevelti*) inhabit temperate coastal forests from northern California to Vancouver Island, British Columbia (Jenkins and Starkey 1984, B.C. Ministry of Forests1990). Excluding Olympic National Park, elk on the Olympic Peninsula were limited to forested habitats that were managed primarily for timber production (Jenkins and Starkey 1984). Populations of elk on Washington's Olympic peninsula have declined since the 1980's (Ferry et al. 2001). A population estimate of 8,610 for elk outside of Olympic National Park was obtained in 2000, indicating a 28 percent decline in elk from the estimated population size of 12,000 in the 1980's (Washington Department of Fish and Wildlife 2004). This decline was attributed to timber management practices, the over harvest of cow elk, and predation; however specific data were either lacking or anecdotal in nature (Olympic Peninsula State-Tribal Elk Working Group 1999). To identify factors that have contributed to the decline of elk on the Olympic Peninsula, the Makah Tribe initiated a study on the Hoko and Dickey game management units, in Clallam County, Washington in March 2000. The objectives of the Tribe's study included a population estimate for the Hoko game management unit, as well as the identification of factors that have influenced the size, stability, and health of elk on the peninsula. The long-term management objective was to restore elk populations to sustainable levels that would allow for cultural, subsistence, and recreational hunting needs in perpetuity.

Coincidental with the decline in elk numbers was the alteration of forested habitats due to increased timber harvesting during the 1980's. Historical timber harvest practices have resulted in widespread even-aged stands that were less than 90 years old (Schroer et al. 1993). Because even-aged coniferous forest lack the interspersion of forage and cover recommended by elk managers (Witmer and deCalesta1985), the increasing prevalence of even-aged timber stands pose a significant problem for the management of elk in the Pacific Northwest (Schroer et al. 1993). The conversion of old-age coniferous forest to even-aged stands has resulted in significant changes in forest structure, stand composition, microclimate, and exposure of elk to hunting related disturbance (Witmer and deCalesta 1983). Increased canopy density, resulting from the succession of young coniferous forest to extensive even-aged stands, has also lead to a reduction in the quantity and quality of available elk forage (Schroer et al. 1993, Washington Department of Fish and Wildlife 2004, Hutchins 2006). Hutchins (2006) reported that female elk on the Hoko and Dickey game management units had a higher level of reproductive success in habitats that contained young stands of timber less than 15 years of age. Conversely, the reproductive success of elk was lower in habitats that were composed of continuous stands of maturing timber. The observed difference was attributed to increased nutritional quality and abundance of elk forage in younger timber seral stages.

Active timber harvesting, and the subsequent conversion of forested areas to even-aged stands, produces both short-term and long-term disturbances on elk. The effects of short-term disturbances include altered movements and habitat use (Edge and

Marcum 1985, Witmer and deCalesta 1985, Cole 1996) and reduced herd fidelity (Peek et al. 1982). Previous studies have reported increased movements of elk in response to logging activities (Beall 1976, Lyon 1979, Lieb 1981, Edge and Marcum 1985). Long-term effects of extensive even-aged timber management included a reduction in forage quality and the avoidance of large portions of habitat (B. C. Ministry of Forests 1990). Several studies have documented the habitat use of elk in the Pacific Northwest (Irwin and Peek 1983, Jenkins and Starkey 1984, McCorquodale et al. 1986, Grenier 1991, Pope 1994, Hutchins 2006). However, the number of studies that have assessed the use of different successional stages of timber by elk has been limited (Irwin and Peek 1983, Witmer and deCalesta 1983, Schroer et al. 1993). Because elk use a wide range of habitats and have been classified as generalist herbivores, a greater knowledge of habitat use was needed for a broad array of successional stages of timber (Irwin and Peek 1983, Schroer et al. 1993).

Increased road density, and a subsequent increase in both hunter access and elk vulnerability, was another consequence of timber harvesting (Schroer et al. 1993, Cole 1996). Although managed forests on the Hoko and Dickey game management units contained relatively high road densities in 2000 (Washington Department of Fish and Wildlife 2004), the use of motorized vehicles had been restricted since 1987. Thus, hunter access was limited to non-motorized forms of transportation (i.e. foot, bicycle, horse; Olympic Peninsula State-Tribal Elk Working Group 1999). Previous research demonstrated that road closures may reduce the vulnerability of elk to hunting pressure (Basile and Lonner 1979, Edge 1982, Cole et al. 1997). However, the effect of hunting

on the Hoko and Dickey game management units had not been investigated. Hunting related disturbance may alter the movements and habitat use of ungulate populations (Sparrowe and Springer 1970, Skovlin 1982, Root et al. 1988). However, because most hunted populations have been influenced by continuous human activity (i.e. vehicular traffic, recreational activities) throughout the year, the observed effects of hunting pressure may have been difficult to separate from other potential sources of disturbance. Long-term human presence may also result in the habituation of elk (Bender and Spencer 1999), thereby limiting the observed effects of seasonal or short-term disturbances. Because roads on the Hoko and Dickey game management units were closed to the vehicular traffic, this study provided a unique opportunity to document the response of elk to seasonal and short-term disturbances without the confounding effects of year round human presence. Knowledge of elk responses to hunting pressure on the Hoko and Dickey game management units will provide local managers insight into the duration, intensity, and framework of future elk hunt programs.

Previous research has demonstrated that movements were practical and measurable parameters for assessing short-term responses of animals to disturbance events (Edge and Marcum 1985, Cole 1996, Naugle et al. 1997), and distance of travel has been shown to be a good indicator of human disturbance (Lieb 1981, Edge and Marcum 1985, Cassirer et al. 1992). For the purposes of this study, human disturbance was defined as hunting, logging, and associated activities that occurred within the home range of radio-collared female elk herds on the Hoko and Dickey game management units. Distances of female elk from roads and logging activities, as well as the distance

moved between paired radio-locations were used to define elk movements. To assess the potential relationship between elk movements and timber management activities, I compared nocturnal and diurnal distances of elk from active logging events. Also, because ungulate movements relative to roads have been used as an indicator of increased use of forest cover in response to human disturbance (Gruell and Roby 1976, Kilgo et al.1998), I compared nocturnal and diurnal distances of elk from roads to assess the affects of hunting pressure.

The objectives of this study were to estimate elk movements, fidelity, home range size, and habitat use relative to sources of human disturbance. Thus, the predictions of this study were that: 1) elk movements would be modified by timber management and hunting activities; 2) measures of herd fidelity would decrease during the hunting period; 3) home range size would increase during the hunting period; and 4) dense even-aged timber stands would be used less than expected based upon habitat availability.

STUDY AREA

The Hoko and Dickey game management units were located in the extreme northwest portion of the Olympic Peninsula, Clallam County, Washington and encompassed approximately 233 km^2. The study area was bounded to the north by the Makah Reservation, on the east by the Straight of Juan de Fuca, and on the west by the Pacific Ocean (Figure 1). The majority of land ownership on the study area was composed of privately owned timberlands that were harvested on a short (50 to 70 years) rotational basis. Limited stands of old growth timber, composed primarily of western hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*), occurred on the western portion of the study area in Olympic National Park, as well as on the southwest portion of the Makah Reservation (Olympic Peninsula State-Tribal Elk Working Group 1999). Residential, farming, and ranching properties were also interspersed along the eastern perimeter of the study area and along the Hoko-Ozette Road.

Elevation on the study area ranged from sea level to just over 600 m at ridge-tops. Climate was markedly influenced by the orographic interaction of maritime air masses and the mountainous topography that was characterized by warm dry summers and cool wet winters (Washington Department of Fish and Wildlife 2004). Year-round temperatures were mild with snow occurring occasionally at higher elevations. Annual precipitation averaged 254 cm, with most occurring as rain from October-March (Makah Forestry 1999). Dominant overstory species included western hemlock, Douglas-fir, Sitka spruce (*Picea sitchensis*), and western red cedar (*Thuja plicata*). Major understory

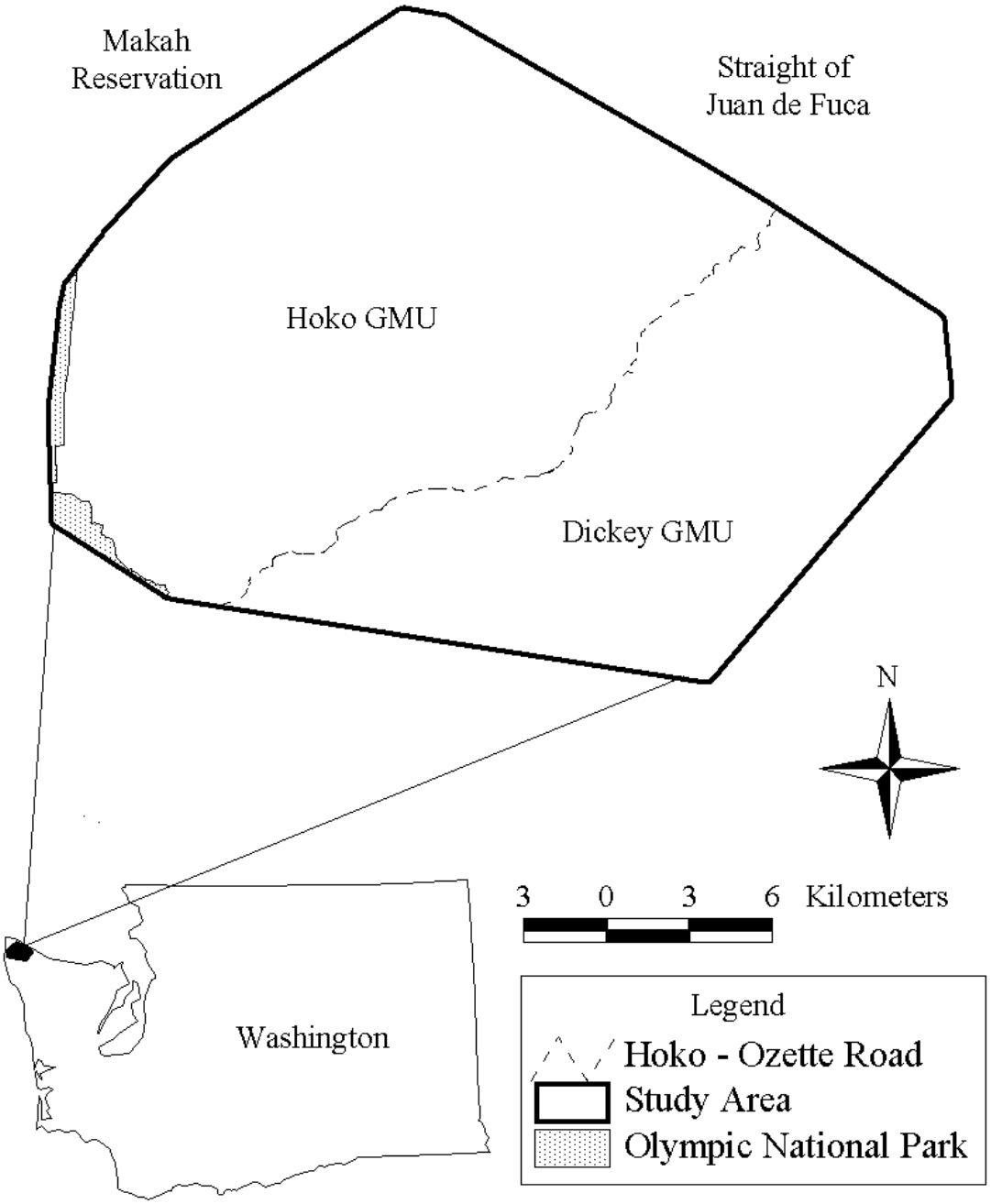

Figure 1. Map of study area used to study movements and habitat use of 10 female Roosevelt elk herds relative to human disturbance on the Hoko and Dickey game management units, Clallam county, Washington from May to November 2000.

species included salal (*Galtheria shallon*), *Vaccinium* sp., Rubus sp., red elderberry (*Sambucus racemosa*), swordfern (*Polystichum munitum*), and lady fern (*Athyrium felix-femina*). Common riparian species included red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*) and *Salix* sp. Herbaceous understories were dominated by a variety of grasses and forbs.

METHODS

Capture and Radio Telemetry

Seven distinct elk herds were observed on the Hoko and Dickey game management units, from which a total of 14 female elk (two adult cows from each elk herd) were captured in March 2000. Elk were located on the study area by helicopter and immobilized using remotely injected darts containing 3 to 4 mg of Carfentanil citrate (Wildlife Pharmaceuticals, Fort Collins, CO). Biologists from the Washington Department of Fish and Wildlife and the Makah department of tribal forestry captured, immobilized, and attached a 1,000 g radio-collar (Model 2-9D, Advanced Telemetry Systems, Isanti, Minnesota) to each elk. To facilitate the detection of elk mortalities, radio-collars contained a mortality-mode switch that doubled the transmitter pulse rate when an animal remained motionless for 8 hours. Capture and handling protocols were reviewed and approved by the Institutional Animal Care and Use Committee of Humboldt State University (IACUC number 99/00.W.80.B).

Radio-collared elk were monitored with a portable receiver (Model R-1000, Communications Specialist, Inc., Orange, CA), a hand-held two-element yagi antenna (Model RA-14 Telonics Telemetry-Electronic Consultants, Mesa, AZ), and an omni vehicle-mounted directional antenna. Observers located elk either by direct visual identification of the animal, or by triangulating on the source of the strongest signal via radio-telemetry. For triangulation, the loudest signal method (Springer 1979) was used to determine the direction of the strongest radio signal from at least three different

identifiable map locations. All compass bearings were spatially distributed (>30°) and measured within 30 min of each other. Resulting elk locations were then plotted to the nearest 20 m grid using the Universal Transverse Mercator (UTM) coordinate system on 7.5^{o}, 1:24,000 USGS topographical maps, and subsequently entered into a geographic information system (GIS, ArcView 3.2 with Spatial Analyst 2.0, Environmental Systems Research Institute, Inc., Redlands, CA).

Two methods of sampling were used to locate elk: point-locations and paired-locations. A point-location was defined as a single radio-location collected within a 24-hour period (Schoener 1981). At least two point-locations were obtained per week for each herd and used to estimate home range size, mean daily movements, and habitat use by elk. Paired-locations were defined as two radio-locations (one nocturnal location and one diurnal location) obtained for a single herd with no more than 11 hours elapsed time between locations (White and Garrott 1990). Nocturnal locations were collected prior to the beginning of logging or hunting activities between 0200 and 0400 hours, while diurnal locations were obtained between 0900 and 1400 hours when potential sources of anthropogenic disturbance (logging or hunting) were present on the study area. The average amount of time elapsed between the collection of a set of paired radio-locations was nine hours, but ranged from five to 11 hours. Paired radio-locations were used to estimate elk movements relative to active logging events, and roads during the hunt and pre-hunt periods.

A single elk herd was randomly selected each day, from which observers either collected point or paired radio-locations. The collection of point-locations was stratified

by time of day, thereby ensuring equal representation of habitat use and movement patterns. The effects of pseudoreplication and temporal autocorrelation were minimized by only using a single location over each 24 hour period to conduct analyses (White and Garrott 1990). Because timber management activities were occasionally unpredictable or periodic, the collection of paired radio-locations was adjusted as needed. Transmitters emitting a mortality signal were immediately retrieved and field necropsies were performed to determine specific cause of death.

Coefficient of Association

Fidelity is an important feature for gauging the effects of human activity on wildlife and has been defined by White and Garrott (1990) as the tendency of animals to remain in or return to a particular space. Fidelity has been proposed to confer individual ecological benefits such as familiarity with seasonal forage and cover (Edge et al. 1985), and the avoidance of predators (Greenwood 1980). Previous studies have used coefficient of association to examine both herd (Galea 1990, Witmer 1981) and home-range fidelity (Jenkins 1979, Edge et al. 1985). To assess the potential effect of hunting pressure upon herd fidelity, coefficient of association values were estimated during the pre-hunt (4 May – 30 August) and hunt (1 September – 21 November) periods. Hunting seasons on the study area included: archery (1 September – 14 September), early muzzleloader (7 October – 13 October), modern firearm (4 November – 12 November), and late muzzleloader (22 November – 15 December) (Washington Department of Fish and Wildlife 2004). Coefficient of asociation values were also used to determine if herd fidelity differed significantly between the following biological seasons: calving (1 May –

15 June), summer (1 July – 14 August), rut (15 August – 1 October), and fall (2 October – 21 November). Coefficient of association was first defined by Cole (1949) as the percentage of locations where two or more marked individuals were located together. Coefficients of associations were calculated as:

$$\text{Coefficient of Association} = 2h / a + b$$

where h was the number of locations that animals a and b were observed together (within 1000 m of each other), a was the total number of observations for animal a, and b was the total number of observations for animal b. Coefficient of association values ranged from zero (no association) to 1.00 (complete association). To minimize spatial pseudoreplication, elk were considered to belong to the same herd when coefficient of association values $\geq$ 0.50 during both the pre-hunt and hunt periods. When duplicate locations were obtained for two associated elk on a given day, one elk was randomly omitted from analyses, thereby minimizing spatial and temporal pseudoreplication. For all subsequent data collection and analyses (movements, home range, and habitat use) the herd represented the sampling unit. A paired t-test (NCSS 2001) was used to determine if a significant difference existed between pre-hunt and hunt period coefficient of association values. A one-way ANOVA (NCSS 2001) was used to determine if mean coefficient of association differed between biological seasons.

Home Range and Elk Movements

Because previous researchers have reported home range estimates throughout the Olympic Peninsula based upon different estimators (Olympic Peninsula State-Tribal Elk Working Group 1999), both fixed kernel (White and Garrott 1990) and minimum convex

polygons (MCP, Hayne 1949) were used to calculate home range size during this study. MCP home ranges were used to delineate the outer most boundaries of areas used by elk herds. However, because MCP estimates are sensitive to peripheral locations (i.e. locations resulting from exploratory movements), they can artificially increase home range size (Powell 2000). Thus, 95% fixed kernels were estimated to assess the spatial use patterns of elk herds as characterized by daily movements and foraging activities. Areas of concentrated use were represented by 50% fixed kernels. Home range sizes were estimated using the ArcView extension Animal Movements (Hooge and Eichenlaub 1997). A paired sample t-test (NCSS 2001) was used to determine if a significant difference existed between pre-hunt and hunt period mean home range estimates.

Both point-locations and a randomly selected location from each set of paired radio-locations (nocturnal or diurnal) were used to estimate mean daily elk movements. Using the ArcView extension Animal Movements (Hooge and Eichenlaub 1997), estimates of mean daily movements were obtained by dividing the linear distance between sequential radio-locations by the number of 24-hour periods during which radio-collared elk were observed. While mean daily movements did not represent an absolute measure of distance moved, they did provide a relative measure of movements that were comparable between study periods (Cole et al. 1997). A one-way ANOVA and a Tukey-Kramer multiple comparison test (NCSS 2001) were used to determine if mean daily movements differed significantly between biological seasons. A paired t-test (NCSS 2001) was used to determine if mean daily movements differed significantly between the pre-hunt and hunt periods.

Using the Arcview extension Nearest Features (Nearest Features 3.8a, Jenness Enterprises, Flagstaff, AZ), paired-locations were used to measure the nocturnal and diurnal distance of elk from roads during the hunt period (Kilgo et al. 1998). Because hunting related mortalities on the Olympic Peninsula were greatest during the months of October and November (Smith et al. 1994), elk were located over a three-month period (September through November) during the hunt period. This observation schedule also included the months of greatest hunter activity, thereby allowing for an estimation of elk movements relative to roads during the hunt period. Although traffic volume was not quantified, three distinct road types were identified on the study area. Roads were classified as primary (unpaved roads that were used by timber management employees, or the general public via non-motorized forms of transportation, and facilitated continuous travel between study area boundaries), secondary (unpaved roads that were used by timber management employees, or the general public via non-motorized forms of transportation, and facilitated travel to remote portions of the study area or between primary roads), and paved (paved highways located on the southern and eastern boundaries of study area that were used to gain access to the study area, or travel to Neah Bay and Olympic National Park). A paired t-test (NCSS 2001) was used to determine if a significant difference existed between mean nocturnal and diurnal distances to roads types.

Paired radio-locations were also used to determine if the net distance between nocturnal and diurnal radio-locations differed with respect to the proximity and source of separate timber management activities (timber harvesting, timber hauling, commercial

thinning, and road maintenance). Paired radio-locations were again used to determine if the distances of elk herds to the combined sources of timber management activities differed between nocturnal and diurnal radio-locations.

Active and proposed timber management activities were identified by contacting local timber companies on a weekly basis. The extent and location of timber management activities were then digitized into a GIS that was used to create a map of all potential disturbance events. The ArcView extension Xtools (Xtools, Oregon Department of Forestry, Oregon State University, Corvallis, OR) was used to estimate the centroid (central area of mass) of each logging operation. The status of logging operations were then verified in the field, as only active timber management activities were used to determine the potential effects of disturbances upon elk movements. For each set of paired-locations, the Arcview extension Nearest Features was used to measure the nocturnal and diurnal distances of elk radio-locations to centriods of active timber management operations. A paired t-test (NCSS 2001) was used to determine if mean nocturnal and diurnal distances to active timber management operations differed significantly.

Habitat Use

An assessment of the error associated with radio-telemetry was needed to accurately assign a habitat type to the locations of each elk herd. Blind tests of all observers were performed by randomly placing test collars that varied in elevation, habitat type, and distance from roads. A modification of the location error method described by Zimmerman and Powell (1995) was used to estimate telemetry error. A

direct measure of error was obtained for each observer by measuring the Euclidian distances between estimated and known locations of test collars. This measure of error was then used as a 95% confidence distance buffer (radius = $\bar{x}$ + 2 *SD*) surrounding each location. This ensured that true locations were located within a circle with that radius, 95% of the time (Zar 1999).

Digitized GIS data (timber stand age, stand extent, water courses, roads, park boundaries, and locations of human made structures) were obtained from the Makah wildlife division manager and used to create a habitat map of the study area. Timber stand age data were digitized from 1976 to 2000 Landsat images and orthophotos (R. McCoy, Makah forestry, personal communication), and were verified through field sampling of randomly generated UTM locations. Twenty-eight vegetation types (Appendix A) were initially identified on the study area, and subsequently reduced to five distinct categories based upon similarities of habitat (Table 1). These data were then used to quantify the proportional amount of habitats that were available and used by elk. To further describe how the habitat use of elk was influenced by the presence of roads and mesic areas, successive distances of elk from roads and permanent sources of water were also analyzed (Table 2). The use of habitat types and successive distances from water were examined over the duration of the study, during biological seasons, and during the pre-hunt and hunt periods. Successive distances from roads were analyzed over the duration of the study, and during the hunt and pre-hunt periods.

Table 1. Description of habitat types used to characterize habitat use by 10 female Roosevelt elk herds on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

Habitat Type	Description[a]
Non-Forest	Characterized by the presence of roads, quarries, slides, residential areas, and human developed habitats. Forage quality was poor to moderate. Security[b] cover was not provided.
Water	Characterized by the presence of non-forested wetlands, deciduous forest, meadows, and riparian areas that were influenced by free flowing or seasonal bodies of water. Forage quality was good to excellent. Security cover was provided when canopy closure exceeded 60%.
Seral Stage 0 – 9 years	Characterized by the presence of herb and shrub/seedling successional stages. Forage quality was good to excellent. Security cover was not provided.
Seral Stage 10 – 21 years	Characterized by the presence of young timber, shrubs, and herbaceous vegetation. Forage quality was moderate to good, especially when canopy closure was below 70%. Security cover was provided when canopy closure exceeded 60%.
Seral Stage > 21 years	Characterized by the presence of dense stands of regenerating conifers, and limited stands of old growth. Forage quality was poor to moderate, especially when canopy closure exceeded 70%. Security cover was provided when canopy closure exceeded 60%. Elk use and movements may be limited due to a lack of quality forage and residual debris resulting from non-commercial thinning.

[a]Adapted from Witmenr and DeCalesta (1983), B.C. Ministry of Forests (1990), and Schroer et al. (1993).

[b]Security cover was defined as moderate to heavily dense forest, riparian, or wetland habitats that provided protection from predators or anthropogenic disturbance (Naugle et al. 1997, Cook et al. 1998).

Table 2. Categories used to characterize the use of successive distances from water and roads by 10 female Roosevelt elk herds on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

Habitat Attribute	Distance (m) Class
Water	
	0 - 50
	51 - 100
	101 - 200
	201 - 400
	401 - 600
	> 600
Primary Road	
	0 - 100
	101 - 200
	201 - 400
	> 400
Secondary Road	
	0 - 100
	101 - 200
	201 - 400
	> 400
Paved Road	
	0 - 600
	> 600

Habitat use and distances from water were analyzed at two spatial scales: population (MCP of all herds) and herd (95% fixed kernel). Successive distances from roads were only analyzed at the population level. Population level analyses were performed by grouping together all radio-locations obtained for each herd. Herd level analyses were performed using each individual herd as the sample unit. Both point-locations and a randomly selected location from each set of paired radio-locations (nocturnal or diurnal) were used to estimate the use of habitat and distance classes at both the population and herd levels. The availability of habitat and distance classes at the population level were delineated by combining the radio-locations of each elk herd to generate 100% MCP polygons during biological seasons, and pre-hunt and hunt periods. Proportions of each habitat type and distance classes within 100% MCP polygons were used to generate expected values at the population level. Habitat and distance classes available at the herd level were delineated by using radio-telemetry locations to generate 95% fixed kernels for each elk herd. Proportions of habitat types or distance classes available within 95% fixed kernel home ranges were used to generate expected values for each herd. Considering all habitats simultaneously, if a chi-square goodness-of-fit test (Zar 1999) indicated a significant difference between observed and expected frequencies, Bonferroni confidence intervals (Neu et al. 1974, White and Garrott 1990) were used to determine habitat types or distance classes that were used greater than expected, less than expected, or in proportion to availability.

RESULTS

Capture and Radio Telemetry

Thirteen elk were captured and radio-collared on the Hoko game management unit and one elk was captured on the north-central portion of the Dickey game management unit. All captured elk were determined to be in good health by a veterinarian. One elk was killed by a mountain lion (*Felis concolor*) in May, 2000 and was therefore excluded from all analyses. A second mortality, for which the cause was unknown, occurred in late August, 2000 (Appendix B). Only pre-hunt data were used for this elk to estimate home range size and movements.

Elk were located from 5 May through 21 November 2000 resulting in an average of 35 $\pm$ 0.28 (mean $\pm$ 1 *SE*) point and 33 $\pm$ 0.55 paired-locations collected for each herd (Appendix B). For all locations, 36% (n = 242) were obtained via direct observation of elk and were therefore considered to be accurate, while all other locations were estimated via radio-triangulation (n = 433). Mean radio-telemetry error distance was 183 m (n = 31, *SD* = 194 m, range = 0 – 749 m).

Coefficient of Association

Fourteen female elk were initially radio-collared on the study area. However, one cow died at the onset of the study and three elk pairs were determined to have coefficient of associations exceeding 0.50 during both the pre-hunt and hunt periods (Appendices C, D, E). Thus, a total of ten elk herds (3 herds composed of two associated cows, and 7 herds composed of a single cow) were used to assess movements and habitat use during

this study. Coefficient of association values did not differ significantly between biological seasons (one-way ANOVA, $F = 0.14$, $df = 3$, $P = 0.93$, Figure 2). A significant difference was also not detected between pre-hunt and hunt periods ($t = 0.05$, $df = 5$, $P = 0.96$, Figure 3, Appendices D, E).

Home Range and Elk Movements

No difference was detected between pre-hunt and hunt period MCP home range estimates ($t = 2.31$, $df = 8$, $P = 0.17$) or 95% fixed kernel estimates ($t = 2.31$, $df = 8$, $P = 0.40$). However, mean 50% fixed kernel estimates were significantly smaller during the pre-hunt than hunt period ($t = 2.70$, $df = 8$, $P < 0.01$, Table 3).

Mean daily movements differed significantly between biological seasons ($F = 5.71$, $df = 3$, $P < 0.01$), with movements during the calving season being significantly less than the rut and fall season movements (Figure 4). Mean daily movements were also significantly greater during the hunt period than pre-hunt period of the study ($t = 3.86$, $df = 8$, $P < 0.01$, Figure 5).

The mean net distance moved between paired radio-locations did not differ significantly (one-way ANOVA, $F = 1.97$, $df = 9$, $P = 0.1$) among the four sources of timber management activities (timber harvesting, timber hauling, commercial thinning, road maintenance) that were identified on the study area. However, when all sources of timber management activities were combined, the mean diurnal distance of elk from logging disturbances significantly exceeded the mean nocturnal distance ($t = 2.82$, $df = 9$, $P < 0.01$).

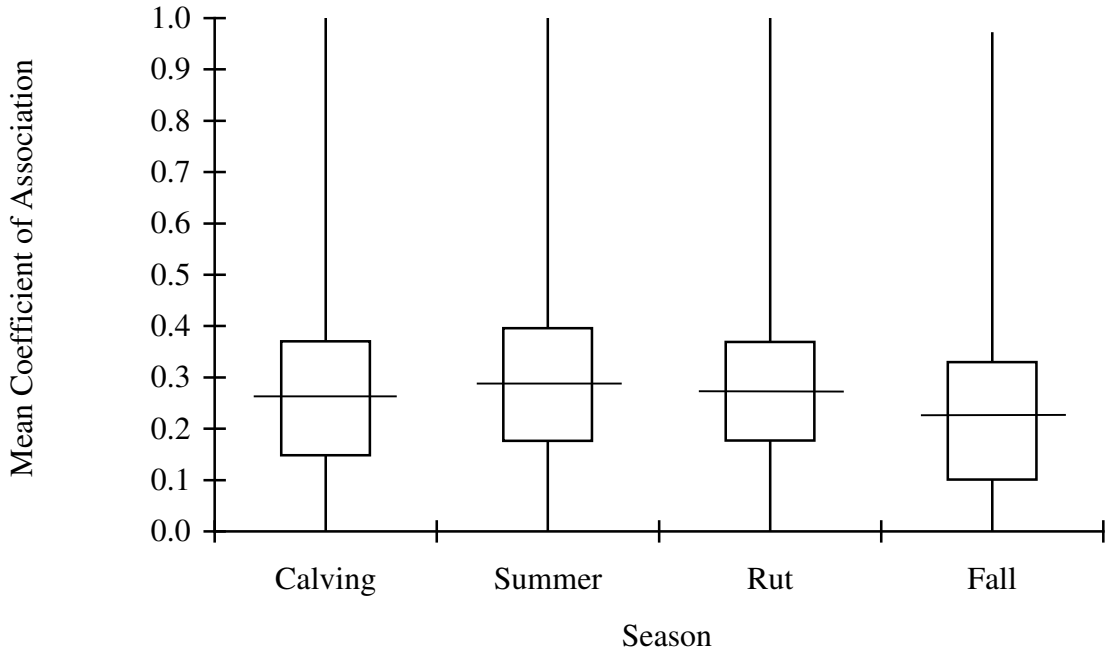

Figure 2. Mean coefficient of association values for six female Roosevelt elk herds during biological seasons on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000 (vertical lines = range, boxes = mean $\pm$ 1 *SE*, horizontal lines = mean).

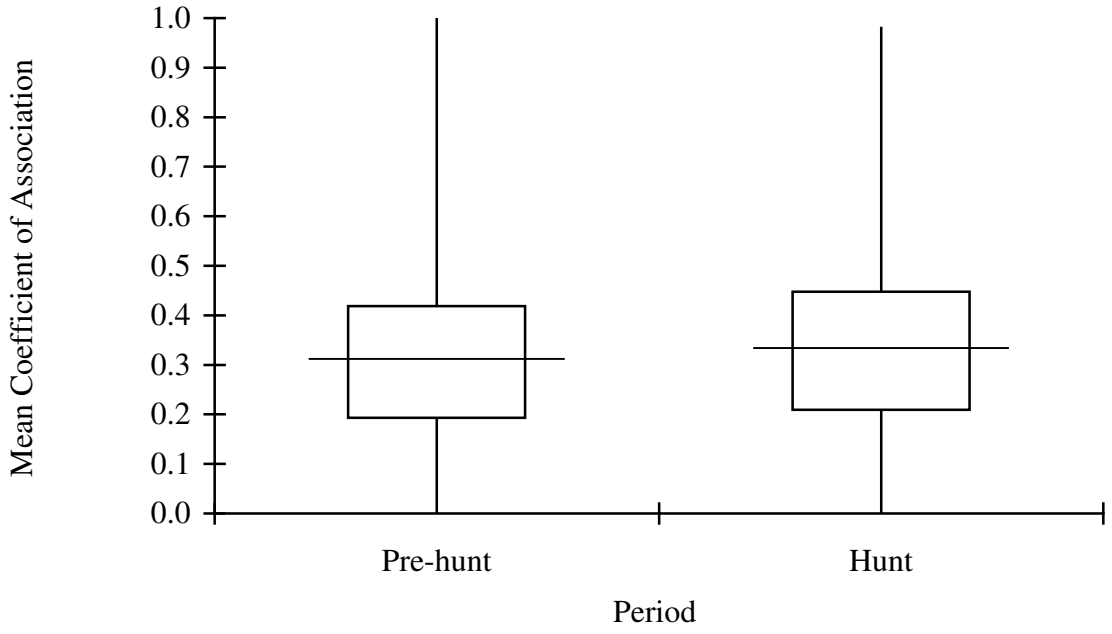

Figure 3. Mean coefficient of association values for six female Roosevelt elk herds during pre-hunt and hunt periods on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000 (vertical lines = range, boxes = mean $\pm$ 1 *SE*, horizontal lines = mean).

Table 3. Mean MCP, 95% fixed kernel, and 50% fixed kernel home range estimates for 10 female Roosevelt elk herds on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

	MCP			95% Fixed Kernel			50% Fixed Kernel		
Elk Herd[a]	Entire Study	Pre-Hunt[b]	Hunt[c]	Entire Study	Pre-Hunt[b]	Hunt[c]	Entire Study	Pre-Hunt[b]	Hunt[c]
011 & 081	18.0	14.5	14.2	21.8	43.2	22.8	4.4	4.3	3.3
039	46.1	39.4	33.5	49.6	40.4	45.9	9.1	5.1	5.6
592	42.2	22.7	34.3	49.6	30.0	40.9	8.0	3.8	11.2
060	37.7	9.8	23.5	49.1	13.1	54.4	6.8	1.6	9.2
551	93.7	9.8	64.8	103.3	13.1	65.4	10.6	1.6	14.2
120 & 482	70.7	43.7	35.3	63.1	52.2	54.7	10.7	9.7	14.8
611 & 630	32.8	23.4	22.1	18.1	17.0	23.0	2.8	3.2	3.2
532	28.1	21.3	16.4	22.7	22.8	23.5	2.2	2.1	3.1
571	20.0	20.0	-	33.3	33.3	-	5.5	5.5	-
652	22.0	18.5	12.8	26.0	24.4	26.3	2.6	3.3	6.6
Mean	41.1	22.3	28.6	43.6	28.9	39.7	6.3	4.0	7.9
SE	7.6	3.6	5.4	8.2	4.2	5.5	1.0	0.8	1.6

[a]Elk with coefficient of association values > 0.50 during pre-hunt and hunt phases of the study were considered to be associated. In such cases, data were combined to create an average home range estimate.
[b]Pre-hunt phase extended from 5 April through 31 August 2000.
[c]Hunt phase extended from 1 September through 21 November 2000.

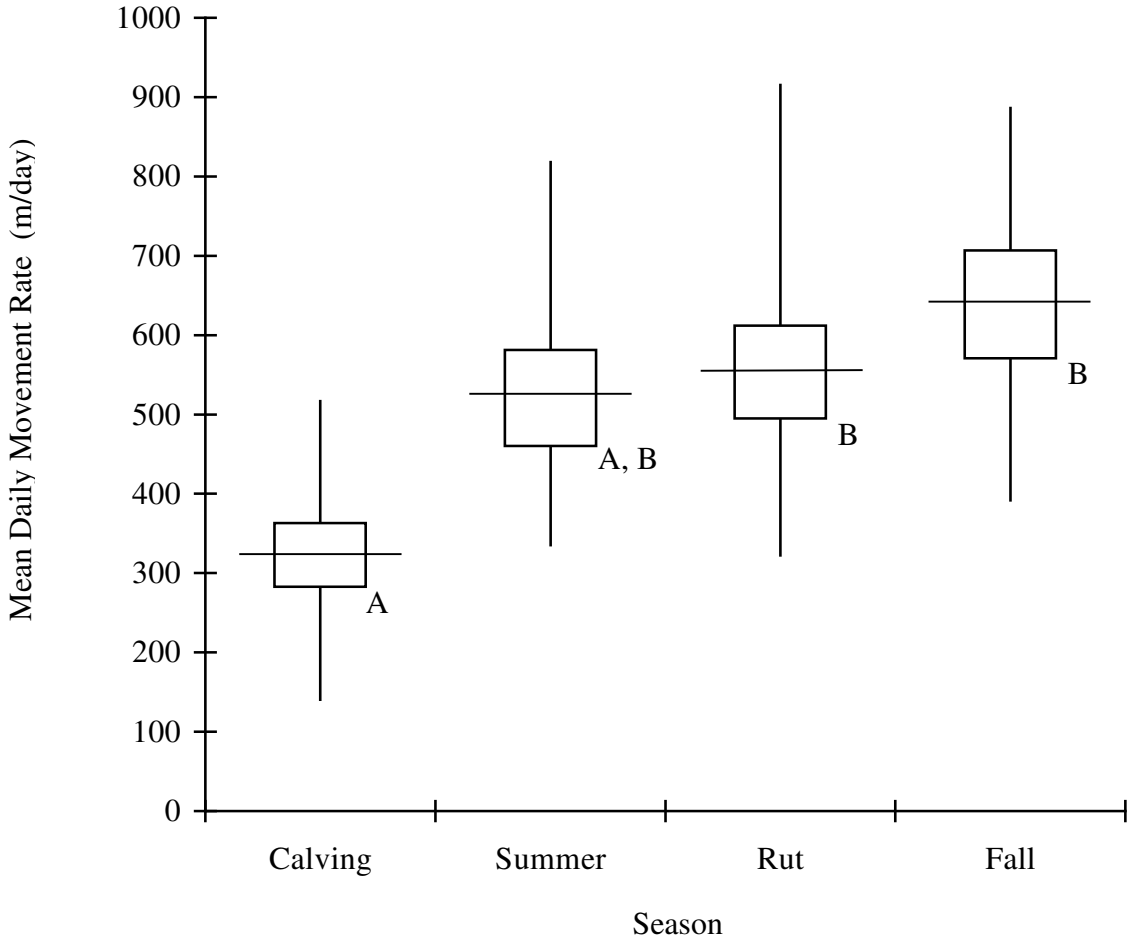

Figure 4. Mean daily movements by 10 female Roosevelt elk herds during biological seasons on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000 (vertical lines = range, boxes = mean ± 1 *SE*, horizontal lines = mean). Mean daily movements denoted with dissimilar letters differed ($P < 0.05$) among biological seasons based upon a Tukey-Kramer multiple comparison test.

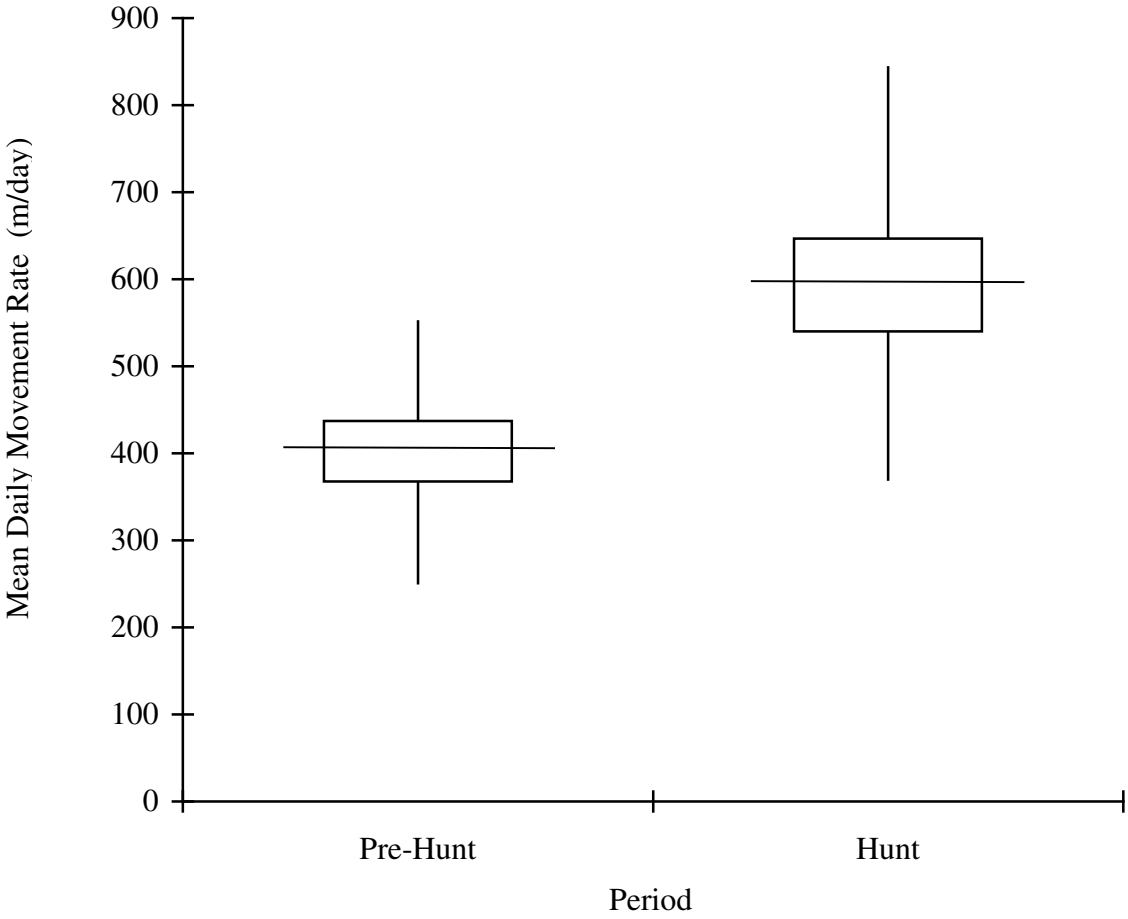

Figure 5. Mean daily movements by 10 female Roosevelt elk herds during pre-hunt and hunt periods on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000 (vertical lines = range, boxes = mean ± 1 *SE*, horizontal lines = mean).

Distances to primary roads during the pre-hunt period did not differ between nocturnal and diurnal paired-locations ($t = 0.99$, $df = 9$, $P = 0.33$, Table 4). Nocturnal distances to primary roads during the hunt period were significantly less than diurnal distances ($t = 3.14$, $df = 8$, $P < 0.01$, Table 4). Nocturnal and diurnal distances to secondary roads also did not differ during the pre-hunt ($t = 1.41$, $df = 9$, $P = 0.17$) or hunt ($t = 0.01$, $df = 8$, $P = 1.99$) periods of the study (Table 4). There was also no significant difference between paired nocturnal and diurnal distances from paved roads during pre-hunt ($t = 0.26$, $df = 9$, $P = 0.80$) or hunt periods ($t = 0.07$, $df = 8$, $P = 0.94$, Table 4).

Habitat Use

Vegetation types and timber stand ages were correctly classified 94.4 % and 97.7% of the time respectively. One elk was omitted from all herd level analyses due to a lack of data (Appendix F), resulting in nine separate habitat and distance class analyses within 95% fixed kernels. However, pre-hunt data from this herd were included in population level (MCP) analyses. Combined data from all elk herds were used to estimate seasonal, pre-hunt, and hunt period use of habitat types and distance classes within MCP home ranges.

Eight of nine elk herds used habitat types different from expected based upon availability within 95% fixed kernel home ranges ($\chi^2 = 291.58$, $df = 4$, $P < 0.01$, Appendices F, G). Two elk herds used water more than expected, three herds used seral stage 0 – 9 years more than expected, and six herds used seral stage > 21 years less than expected (Table 5, Appendices F, G).

Table 4. Nocturnal and diurnal distances of 10 female Roosevelt elk herds from roads during pre-hunt and hunt periods on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

	Pre-Hunt Period				Hunt Period			
	Nocturnal Distance (m)		Diurnal Distance (m)		Nocturnal Distance (m)		Diurnal Distance (m)	
Road Type	$\bar{x}$	$\pm SE$	$\bar{x}$	$\pm SE$	$\bar{x}$	$\pm SE$	$\bar{x}$	$\pm SE$
Primary	1706	227	1537	209	1322	171	1809	184
Secondary	473	67	583	81	516	53	515	67
Paved	19226	1753	19312	1719	20089	1182	20068	1170

Table 5. Number of elk herds that used habitat types significantly ($P < 0.05$) less than, greater than, or equal to the expected proportion of use based on habitat availability (Appendices F, G) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

	Use Compared with Expected[a]		
Habitat Type	Greater Than	Not Different	Less Than
Non-Forest	0	9	0
Water	2	7	0
Seral Stage 0 – 9 years	3	6	0
Seral Stage 10 – 21 years	0	9	0
Seral Stage > 21 years	0	3	6

[a]Expected values were calculated using proportions of habitat types available within 95% fixed kernel home range for each elk herd.

Seasonal use of available habitat within MCP home ranges was disproportionate to habitat availability. Non-forested habitat was used in greater proportion to availability over the duration of the study (χ^2 =253.53, df = 4, P < 0.01, Appendices H, I). Water was used in greater proportion to availability throughout all seasons (Appendices H, I), except during the rut when it was used equal to availability. Seral stage 0 – 9 years was used in greater proportion to availability over the duration of the study (χ^2 = 253.53, df = 4, P < 0.01, Appendices H, I), and during the calving season (χ^2 = 19.53, df = 4, P < 0.01, Appendices H, I) and pre-hunt period (χ^2 = 67.72, df = 4, P < 0.01, Appendices H, I). Elk use of seral stage > 21 years was significantly less than expected throughout all seasons (Appendices H, I), except during the hunt period when it was used equal to availability.

Two of nine elk herds used distances from water different than expected based upon availability within 95% fixed kernel home ranges (χ^2 = 164.80, df = 5, P < 0.01, Appendices J, K). Both herds used distances within 50 m of water in greater proportion to availability, and distances exceeding 400 m less than expected (Table 6, Appendices J, K).

Seasonal use of distances from water, based upon availability within MCP home ranges, was disproportionate to availability. Distances with 50 m of water were used in greater proportion to availability throughout all seasons (Appendices L, M), except during the summer when distances were used equal to availability. Distances exceeding 400 m from water were used less than availability throughout all season (Appendices L, M), except during the calving season when distances were used equal to availability.

Table 6. Number of elk herds that used successive distances from water significantly ($P < 0.05$) less than, greater than, or equal to the expected proportion of use based on habitat availability (Appendix J) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

	Use Compared with Expected[a]		
Water Class (m)	Greater Than	Not Different	Less Than
0 – 50	2	7	0
51 – 100	0	9	0
101 – 200	0	9	0
201 – 400	0	9	0
401 – 600	0	7	2
> 600	0	7	2

[a]Expected values were calculated using proportions of water distance classes available within 95% fixed kernel home range for each elk herd.

Distances to primary roads, based upon availability within MCP home ranges, were used in proportion to availability over the duration of the study and during the pre-hunt period (Appendices N, Q). However, during the hunt period, elk used distances within 200 m of primary roads significantly less than expected and distances exceeding 400 m in greater proportion to availability ($\chi^2 = 415.10$, $df = 3$, $P < 0.01$, Appendices N, Q).

Elk use of distances to secondary roads within MCP home ranges was disproportionate to availability. Elk used distances within 100 m of secondary roads less than expected and distances between 100 and 400 m in greater proportion to availability over the duration of the study ($\chi^2 = 103.83$, $df = 3$, $P < 0.01$), and during pre-hunt ($X^2 = 55.04$, $df = 3$, $P < 0.01$) and hunt periods ($\chi^2 = 49.22$, $df = 3$, $P < 0.01$, Appendices O, Q).

Distances to paved roads within MCP home ranges were used in proportion to availability over the duration of the study and during the pre-hunt period (Appendices P, Q). However, during the hunt period, elk used distances exceeding 600 m from paved roads in greater proportion to availability and distances within 600 m less than expected ($\chi^2 = 3.21$, $df = 1$, $P < 0.01$, Appendices P, Q).

DISCUSSION

The objective of this study was to determine if the behavior of female elk was modified by sources of anthropogenic disturbance. Two major forms of human disturbance (timber management and hunting) were identified on the Hoko and Dickey game management units, both of which modified the movements and habitat use of elk. Ten elk herds had adequate samples to establish their home range size, habitat use, and movement patterns. Because the spatial scale of elk movements was much greater than the error associated with estimating the position of elk herds using radio-telemetry, each variable was treated as accurate during this study.

Before assigning changes in fidelity to hunting activities, the natural impact of seasonal differences in forage, predation, and water availability had to be known. Thus, to determine the influence of biological seasons (calving, summer, rut, and fall) upon herd fidelity, coefficient of association values were calculated for all radio-collared elk. For all individual elk combined, coefficient of association did not differ significantly between biological seasons. Coefficient of association also did not differ prior to or during the hunt period. Thus, the social cohesion of elk herds was maintained regardless of biological season or hunt period.

Home Range, Movements, and Habitat Use

Prior to assessing how elk movements or spatial use patterns were influenced by hunting or timber management activities, the character of these parameters were compared to other elk populations. Elk home range size has been influenced by

variations in resource distribution (Schoener 1981), ability to traverse across different habitat types (Craighead et al. 1973, Anderson and Rongstad 1989), and activities related to breeding and parturition (Craighead et al. 1973). Mean MCP home range estimates for elk within the western United States varied from 1 km^2 in coastal Oregon to 90 km^2 on the Olympic Peninsula, Washington (Schroer 1987). During this study, home range size varied from 18 – 94 km^2 (MCP), 18 – 103 km^2 (95% fixed kernel), and 2 – 11 km^2 (50% fixed kernel). Because the home range estimates generated during this study were comparable in size to other elk studies (Franklin et al. 1975, Witmer and deCalesta 1985, Fischer 1987, Pope 1994, Millspaugh 1995, Cole 1996), they provided a base-line for an assessment of how human disturbances influenced the spacial use patterns of elk on the Hoko and Dickey game management units.

Ungulate movements may be linked to available habitat, frequency and intensity of disturbance, and the degree of previous human exposure (Kilpatrick and Lima 1999). Several researchers have attempted to correlate the timing of ungulate movements with various natural and human caused phenomenon (McCullough 1964, Nelson and Mech 1981, Garrott et al. 1987). Thus, in order to assess the effects of seasons upon elk movements, mean daily rates of movement were compared over four biological seasons (calving, summer, rut, fall). Mean daily movements were greatest during the fall and least during the calving season. Because the fall season overlapped hunt period during this study, increased fall movements were likely the result of hunting activity. Schroer (1987) also attributed increased daily movements over a similar time period to hunting in the Olympic Mountain Range, Washington. Also, Harper (1971) reported that Roosevelt

elk calves were not prepared to traverse long distances for approximately one month following birth. Thus, the decreased movements of female elk during the calving season were most likely the result of reduced calf mobility.

Mesic areas have been associated with abundant high quality forage, and were therefore considered to be important elk habitat during this study (Hanley 1984, Collins and Urness 1983, Hutchins 2006). Several studies have reported the habitat use of Roosevelt elk based upon distances from sources of water (Witmer and deCalesta 1983, Grenier 1991, Pope 1994, Cole 1996). Witmer and deCalesta (1983) reported that female elk were closest to sources of water during the calving season and were generally within 190 m of water throughout the year. Rocky Mountain elk (*Cervus elaphus nelsoni*) were also seasonally associated with permanent sources of water such as riparian areas (Marcum 1975, Pederson and Adams 1976, Pederson et al. 1979). With the objective of determining how mesic areas influenced the spatial use patterns of elk on the Hoko and Dickey game management units, I analyzed the use of successive distances of elk from permanent sources of water. At both the population (MCP all herds) and herd levels (95% fixed kernel), elk used distances within 50 m of water more than expected and distances exceeding 400 m less than expected. Thus, because elk consistently used areas near water more than expected and areas more distant from water less than expected, the results of this study suggest that mesic areas (i.e riparian areas, wetlands, bogs) may be important habitats that were used by elk throughout the year. This may be attributed to habitat components such as a cooler climate, abundant forage, and vegetative cover that have been associated with permanent sources of water. Furthermore, any disturbance that

alters the basic habitat use patterns of ungulates may have associated cost to lactation, forage acquisition, or predator avoidance (Edge and Marcum 1985, Schroer et al. 1993).

Timber Harvesting as a Disturbance Factor

Human disturbance that occurs during timber management activities may result in the avoidance of habitat by elk, altered movements, and reduced forage abundance and herd fidelity (Peek et al. 1982, Edge and Marcum 1985, Schroer et al. 1993). The response of elk to timber management activities may differ with respect to specific types of disturbance. Therefore, four sources of logging related disturbance (timber harvesting, timber hauling, commercial thinning, and road maintenance) were identified on the study area. When the four sources of disturbance were combined, diurnal distances of female elk herds from timber management activities significantly exceeded nocturnal distances. Thus, elk moved away from logging activities during the day when human disturbance was most prevalent on the study area. Previous research has demonstrated that short-term movements of elk will return to pre-disturbance levels once the source of disturbance has ended (Wright 1983, Edge and Marcum 1985, Cassirer et al. 1992). Thus, the short-term effect of timber management activities on elk movements was probably temporary. However, because elk generally have a higher rate of mortality during the first year of life, increased energy demands and stress resulting from consistent human disturbance may lead to decreased reproductive success or the abandonment of traditional calving areas (Kuck et al. 1985, Vore 2001). Another possible consequence of human disturbance may be the avoidance of available habitat and the subsequent use less favorable areas (Batcheler 1968).

Use of habitats by ungulates has been influenced by the need to maximize net energy intake, minimize predation and thermal stress, and maintain social contacts (Aycrigg and Porter 1997, Kie 1999, Porter et al. 2002). Geist (1982) also suggested that female ungulates differentially used habitats that maximized offspring survival. However, if human disturbance results in elk inhabiting habitats not previously used or causes elk to avoid habitats that would otherwise be beneficial, the health or reproductive success of elk could be compromised (Geist 1982, Skovlin 1982, Hutchins 2006). During this study, the habitat use of radio-marked elk was analyzed at both the population (MCP of all herds) and herd (95% fixed kernel) level. The objective was to determine if particular timber seral stages were used more or less than expected. Based upon habitat availability within seasonal MCP home ranges, elk used non-forested areas, water, and seral stage 0 – 9 years more than expected. Conversely, seral stage > 21 years was used less than expected across all seasons, except during the hunting period when it was used equal to availability. Based upon habitat availability within 95% fixed kernels, two of nine elk herds used water more than expected, and three of nine herds used seral stage 0 – 9 years more than expected. Conversely, six of nine elk herds used seral stage > 21 years less than expected. Hutchins (2006) found that female elk on the Hoko and Dickey game management units were more reproductively successful in areas containing young stands of timber less than 15 years of age. Conversely, reproductive success was lower in habitats that were comprised of continuous stands of maturing timber. The observed difference was attributed to higher forage quality and forage abundance in younger timber age classes. Hence, seral stage 0 – 9 years may have been used more than

expected due to high levels of forage biomass and higher quality nutrition, both of which were associated with younger seral communities (Schroer 1987). Schroer et al. (1993) also reported that forage abundance was greatly reduced in even aged stands between the ages of 16 and 150 years. This may explain the less than expected use of seral stage > 21 years during this study. Thus, timber management activities produced both short-term disturbances that modified elk movements, as well as long-term disturbances that reduced the availability of quality habitats 20 years after harvesting. Both levels of disturbance have energetic consequences for elk, and therefore have the potential to reduce elk productivity on the Hoko and Dickey game management units.

Hunting as a Disturbance Factor

Mammals may respond to disturbances by humans by reducing activity to areas, habitats, and times of day where encounters with humans were minimal (Geist 1971). An increase in home range size has been reported for White-tailed deer (*Odocoileus virginianus*) due to ranching operations (Hood and Inglis 1974), snowmobile activity (Dorrance et al. 1975), and hunting (Root et al. 1988). Peek et al. (1982) suggested that high levels of human disturbance may result in the abandonment of home ranges by elk. Ward et al. (1980) also demonstrated that even productive habitats may be abandoned by elk if human disturbance was excessive. Thus, to determine the influence of hunting on herd fidelity, coefficient of association values were calculated both prior to and during the hunt period. For all herds combined, coefficient of association did not differ significantly between the pre-hunt and hunt periods. However, one herd (060 + 551) that exhibited complete association during the pre-hunt period (Appendix D) abandoned their

home range on the second day of the hunt period. One elk moved to the extreme southeast portion of the study area, while the other joined a separate group of radio-marked elk in the northeast portion of the study area. The two radio-marked elk from this herd had a complete lack of association thereafter (Appendix E). Prior to the beginning of the hunt period, this herd's home range was adjacent to two major highways bordering the study area, and was therefore often visible to daily vehicular traffic. This herd's home range also overlapped the only primary road that was open to public-use vehicular traffic on the study area. Therefore, herd fidelity as expressed by conspecific associations appears to have been inversely related to the proximity of elk to public-use roads during the hunt period. The ultimate consequences of roads that are open to public-use vehicular traffic include increased energetic demands, as well as the avoidance of habitats that are potentially beneficial to elk.

Habitat use and home range sizes were estimated to determine the potential effects of hunting upon the spatial use patterns of elk. No difference was detected between pre-hunt and hunt period MCP or 95% fixed kernel estimates. However, 50% fixed kernel (concentrated use areas) estimates were significantly larger during the hunt than pre-hunt period. Seral stage > 21 years was also used less than expected during all phases of this study, except during the hunt period during which time it was used equal to availability. The observed increase in 50% fixed kernel estimates, as well as the increased use of seral stage > 21 years during the hunt period may have been the result of increased use of cover in response to hunter presence. The expansion or abandonment of

concentrated use areas may result in a greater risk of predation, increased energetic demands, poorer forage availability, and decreased reproductive success.

Previous studies have demonstrated that hunted elk may respond to human disturbance by increasing movements, (Sparrowe and Springer 1970, Root et al. 1988), avoiding areas near roads (Ward 1976, Burbridge and Neff 1976), and seeking out areas of forest cover (Marshall and Whittington 1969, Irwin and Peek 1983). Rocky mountain elk have been found to use habitats with forest cover during periods of increased human disturbance (Mclean 1972, Bohne 1974, Marcum 1975). White-tailed deer have also been shown to increase movements and shift home range centers to areas of permanent cover in response to hunting (Marshal and Whittington 1969, Dorance et al. 1975, VerCauteren and Hygnstrom 1998). In order to determine the effects of hunting upon elk movements, both long-term (mean daily rates) and short-term (nocturnal vs. diurnal) movements were compared during the pre-hunt and hunt periods of this study. Mean daily movements during the hunt period significantly exceeded pre-hunt movements. Nocturnal distances of elk from primary and paved roads were also significantly less than diurnal distances during the hunt period. Thus, elk avoided main travel routs and used areas of greater cover in response to hunting activity. Increased movements of elk in response to hunting related disturbance may result in greater energetic demands which can have serious consequences on the reproductive success of female elk (Geist 1971).

Although elk have been shown to use roads as travel corridors (Marcum 1975, McCoy 1986), previous studies have demonstrated that anthropogenic disturbance may elicit behavioral changes that result in areas adjacent to roads being avoided, ultimately

leading to a reduction in habitat availability (Rost and Bailey 1979, Edge 1982, Starkey et al. 1982). Hence, in order to determine if hunting displaced elk from habitats that were being used, I analyzed successive distances of elk from three road types on the study area (primary, secondary, paved). Although each road type accommodated the use of motorized vehicles, the general public was restricted to non-motorized forms of transportation (i.e. foot, bicycle, horse) when using primary or secondary roads. Several researchers have investigated the influence of roads upon the habitat use of elk. Although these studies may differ with respect to road types or modes of transportation, their findings allow for useful comparisons with this study. Marcum (1975), and Edge (1982) suggested that elk avoided human activity on roads and not the roads themselves, and Gruel and Roby (1976) found that elk only avoided roads during the hunting season. Witmer and deCalesta (1985) reported that Roosevelt elk cows used areas within 500 m of paved roads and areas within 125 m of spur roads less than expected. Cole (1996) found that Roosevelt elk avoided areas within 150 m of roads and used areas exceeding 150 m more than expected. Excluding the hunt period, distances of elk from primary roads were used in proportion to availability during this study. However, during the hunt period, distances within 200 m of primary roads were used significantly less than availability, and distances exceeding 400 m were used in greater proportion to availability. Based upon personal observation, using non-motorized forms of transportation, hunters used primary roads as main travel routs during this study. Therefore, the increased use of primary roads by hunters may account for their lack of use by elk during the hunt period. Distances of elk from secondary roads were used in a

similar manner during all phases of this study, with distances within 100 m being used less than availability and distances between 100 and 400 m being used in greater proportion to availability. Because secondary roads were the most prevalent road type throughout the study area, the greater than expected use of this road type was most likely a consequence of its relatively high density. Excluding the hunt period, distances of elk from paved roads were used in proportion to availability. However, during the hunt period distances within 600 m of paved roads were used less than availability and distances exceeding 600 m were used in greater proportion to availability. Based upon personal observation, paved roads received an increased level of hunting related vehicular traffic during the hunt period. Perry and Overly (1976) and Witmer and deCalesta (1985) also reported that paved roads had greater impacts upon elk movements than secondary or spur roads. Therefore, the avoidance of paved roads during the hunt period may have been the result of elk responding to increased vehicular traffic and associated hunter disturbance by moving towards the interior portion of the study area. These results indicatee that hunting related disturbances elicited behavioral responses from elk that resulting in altered movements and habitat use patterns, as well as an increased use of cover (timber seral stage > 21 years). Although the degree of habitat displacement appears to have been dependent upon road type, the displacement of elk from areas adjacent to roads during this study was consistent with other studies of ungulate hunting within the western United States (Edge 1982, Hershey and Leege 1982, Wright 1983).

MANAGEMENT IMPLICATIONS

Elk movements and habitat use were modified by anthropogenic disturbances that resulted from timber management activities during this study. Diurnal distances to logging disturbances were consistently greater than nocturnal distances, indicating that elk increased their movements and were displaced from habitats that were being used. Logging disturbances may displace elk from critical habitats such as calving areas. A potentially serious consequence of such displacements may be a reduction in the reproductive success of cows (Phillips and Alldredge 2000). If resource managers mitigated or restricted the proximity of logging operations to calving areas, especially during the calving season, it may be possible to either limit or reduce the effects of timber management activities on the study area. However, if calving areas are found to be widely dispersed across the study area such management stratagies may not be feasable.

Commercial timber harvesting produces widespread changes in successional plant communities and, thus, has been a major factor affecting the abundance and distribution of ungulates (Monthey 1984). Even-aged timber stands greater than 21 years of age were used less than expected by elk during this study. Conversely, young seral stages between the age of zero and nine years of age were used more than expected. Thus, silvicultural alternatives to even-aged stand management, such as patch-cuts (i.e. < 5 acres) or uneven-aged timber management coupled with commercial thinning may improve or create a greater interspersion of forage and cover for elk. Elk also used habitats associated with permanent sources of water and distances within 50 m from water more

that expected during this study. Wet meadows and mesic habitats were identified as areas that have provided abundant amounts of high quality forage (Collins and Urness 1983, Hanley 1984, Hutchins 2006), and riparian areas in western Washington have been used more than expected throughout the year (Schroer et al 1993). Hutchins (2006) also found that the reproductive success of female elk was positively related to the availability of marsh and riparian habitats on the Hoko and Dickey game management units. These habitats were associated with the presence of forage species (i.e. grasses, sedges, and forbs) that contained high levels of digestible protein (Hutchins 2006). Thus, because elk productivity has been linked to habitats that are associated with permanent sources of water, assuring that adequate buffers are maintained around rivers, streams, and wetlands may provide long-term benefits for elk.

Mean daily rates of movement, diurnal distances from roads, and the size of 50% fixed kernel estimates were significantly larger during the hunt period. Also, one elk herd, whose home range overlapped the only road that was open to public-use vehicular traffic, abandoned its home range during the hunting season. Thus, elk that were exposed to vehicular traffic during the hunting season were more vulnerable to hunting and associated disturbances. Hunting disturbances may alter the distribution of elk, leading to a reduction in habitat availability, greater risk of predation, and increased energy cost. It may be possible to minimize hunting related disturbances by restricting the use of motorized vehicles on public-use roads during the hunting season. Maintaining the closure of all other roads that have traditionally prohibited the use of public-use vehicles may also limit sources of anthropogenic disturbance. The continued lack of road

accessibility to humans on the Hoko and Dickey game management units will most likely contribute to the productivity of elk.

Finally, prior to establishing the duration and intensity of the hunting season, it may be beneficial for resource managers to assess the proportion of landscapes that are composed of young seral stages. Previous research has demonstrated that young successional stages of timber are associated with abundant amounts of high quality forage (Witmer and deCalesta 1983, Schroer et al. 1993, Hutchins 2006). Although the reproductive success and numbers of elk may initially increase under such conditions, elk may become increasingly vulnerable to hunting as the amount of open habitat (seral stage 0 – 9 years) increases. Thus, the framework of future elk hunting programs could be adjusted as the amount of open habitats comprised of seral stage 0 – 9 years changes over time.

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Appendix A. Vegetation types and timber stand ages identified on the Hoko and Dickey game management units, Clallam County, Washington, 2000. Vegetation types and timber stand ages were grouped into unique vegetation categories or groups for statistical purposes.

Vegetation Type	Stand Age (years)	Description of Dominant Vegetation	Vegetation Category	Vegetation Group
Timber	0	western hemlock, Douglas-fir	Timber Age 0	Timber Age 0 - 9
Timber	1	western hemlock, Douglas-fir	Timber Age 0 - 9	Timber Age 0 - 9
Timber	2 - 3	western hemlock, Douglas-fir	Timber Age 0 - 9	Timber Age 0 - 9
Timber	4	western hemlock, Douglas-fir	Timber Age 0 - 9	Timber Age 0 - 9
Timber	5	western hemlock, Douglas-fir	Timber Age 0 - 9	Timber Age 0 - 9
Timber	6 - 7	western hemlock, Douglas-fir	Timber Age 0 - 9	Timber Age 0 - 9
Timber	10 - 11	western hemlock, Douglas-fir	Timber Age 10 - 21	Timber Age 10 - 21
Timber	10 - 12	western hemlock, Douglas-fir	Timber Age 10 - 21	Timber Age 10 - 21
Timber	13 - 15	western hemlock, Douglas-fir	Timber Age 10 - 21	Timber Age 10 - 21
Timber	16 - 18	western hemlock, Douglas-fir	Timber Age 10 - 21	Timber Age 10 - 21
Timber	19 - 21	western hemlock, Douglas-fir	Timber Age 10 - 21	Timber Age 10 - 21
Timber	22 - 23	western hemlock, Douglas-fir	Timber Age > 21	Timber Age > 21
Timber	> 24	western hemlock, Douglas-fir	Timber Age > 21	Timber Age > 21
Timber	> 78	western hemlock, Douglas-fir	Timber Age > 21	Timber Age > 21
Pond	n/a	Water	Water	Water
Lake	n/a	Water	Water	Water

Appendix A. Vegetation types and timber stand ages identified on the Hoko and Dickey game management units, Clallam County, Washington, 2000. Vegetation types and timber stand ages were grouped into unique vegetation categories or groups for statistical purposes. (continued)

Vegetation Type	Stand Age (years)	Description of Dominant Vegetation	Vegetation Category	Vegetation Group
Slide	n/a	Hillside Slide Area, Mud, Earth	Non-Forest	Non-Forest
Quarry	n/a	Gravel, Bare Ground	Non-Forest	Non-Forest
Pasture / Prairie	n/a	Grass	Pasture	Non-Forest
Marsh	n/a	Skunk Cabbage, Willow, Sedge	Marsh	Water
Residential	n/a	Residential Houses, Yards	Non-Forest	Non-Forest
Paved Road	n/a	Paved Highway	Non-Forest	Non-Forest
Primary Road	n/a	Gravel, Bare Ground	Non-Forest	Non-Forest
Secondary Road	n/a	Gravel, Bare Ground	Non-Forest	Non-Forest
Developed	n/a	Non-Residential Property	Non-Forest	Non-Forest
Olympic National Park	> 100	western hemlock, Douglas-fir	Timber Age > 21	Timber Age > 21
Riparian	Varies	Vegetated Areas Adjacent to Rivers and Streams	Riparian	Water

Appendix B. Location data, radio days, and fate of 14 female Roosevelt elk on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

Elk Frequency	Point Locations [a]	Paired Locations [b]	Total Locations [c]	Visual Ovservations (%)	Radio Days [d]	Mortality Source
011	30	36	48	0.04	227	-
039	40	32	56	0.29	224	-
060	38	26	51	0.33	226	-
081	30	38	49	0.08	231	-
120	37	46	60	0.70	227	-
482	38	44	60	0.69	227	-
532	44	24	56	0.21	225	-
551	39	42	60	0.55	229	-
571	23	2	24	0.17	120	Unknown
592	44	28	58	0.29	227	-
611	35	36	53	0.30	224	-
630	32	36	50	0.30	224	-
652	31	38	50	0.44	225	-
562 [e]	0	0	0	0.00	0	Mt. Lion
Total	461	428	675	-	-	-
Mean	35	33	52	0.34	218	-
SE	1.60	3.10	2.60	0.00	8.20	-

[a] Single location obtained for an individual elk over a 24 hour period.
[b] Two locations obtained for an individual elk, with the first obtained between 0100 - 0400 and the second between 0900 - 1300.
[c] Equal to the total number point-locations combined with paired-locations spaced in time by $\geq$ 24 hrs.
[d] Total number of days an individual cow was monitored over the duration of the study.
[e] Elk 562 was omitted from all analyses due to lack of data.

Appendix C. Coefficient of association values for 13 female Roosevelt elk over the duration of the study on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

Elk	Elk Frequency										
Frequency	011	039	060	081	120	482	532	551	592	611	630
039	0.00										
060	0.00	0.00									
081	0.69	0.00	0.00								
120	0.00	0.00	0.00	0.00							
482	0.00	0.00	0.00	0.00	0.86						
532	0.00	0.00	0.00	0.00	0.00	0.00					
551	0.00	0.00	0.60	0.00	0.40	0.40	0.00				
592	0.00	0.51	0.00	0.00	0.00	0.00	0.10	0.00			
611	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
630	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	
652	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D. Pre-hunt season coefficient of association values for 13 female Roosevelt elk on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

Elk	Elk Frequency										
Frequency	011	039	060	081	120	482	532	551	592	611	630
039	0.00										
060	0.00	0.00									
081	0.74	0.00	0.00								
120	0.00	0.00	0.00	0.00							
482	0.00	0.00	0.00	0.00	0.76						
532	0.00	0.00	0.00	0.00	0.00	0.00					
551	0.00	0.00	1.00	0.00	0.00	0.00	0.00				
592	0.00	0.19	0.00	0.00	0.00	0.00	0.20	0.00			
611	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
630	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	
652	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix E. Hunting season coefficient of association values for 13 female Roosevelt elk on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

	Elk Frequency										
Frequency	011	039	060	081	120	482	532	551	592	611	630
039	0.00										
060	0.00	0.00									
081	0.62	0.00	0.00								
120	0.00	0.00	0.00	0.00							
482	0.00	0.00	0.00	0.00	0.98						
532	0.00	0.00	0.00	0.00	0.00	0.00					
551	0.00	0.00	0.04	0.00	0.91	0.89	0.00				
592	0.00	0.86	0.00	0.00	0.00	0.00	0.00	0.00			
611	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
630	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	
652	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix F. Simultaneous confidence intervals using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the habitat use of female Roosevelt elk herds (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Habitat Type	Expected	Actual (p_i)	Lower CI	Upper CI
Herd 1 (n^a = 67)				
Non-Forest	0.02	0.02	0.00	0.05
Water	0.08	0.31	0.17	0.46
Seral Stage 0 – 9 years	0.05	0.02	0.00	0.05
Seral Stage 10 – 21 years	0.27	0.16	0.05	0.28
Seral Stage > 21years	0.58	0.49	0.34	0.65
Herd 2 (n = 56)				
Non-Forest	0.02	0.13	0.01	0.24
Water	0.06	0.12	0.00	0.21
Seral Stage 0 – 9 years	0.01	0.05	0.02	0.13
Seral Stage 10 – 21 years	0.31	0.23	0.09	0.38
Seral Stage > 21 years	0.60	0.48	0.31	0.65
Herd 3 (n = 50)				
Non-Forest	0.07	0.06	0.00	0.15
Water	0.03	0.04	0.00	0.11
Seral Stage 0 – 9 years	0.21	0.36	0.19	0.54
Seral Stage 10 – 21 years	0.07	0.02	0.03	0.07
Seral Stage > 21 years	0.62	0.52	0.34	0.70

Appendix F. Simultaneous confidence intervals using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the habitat use of female Roosevelt elk herds (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. (continued)

			Confidence Interval Lower ≤ p_i ≤ Upper	
Habitat Type	Expected	Actual (p_i)	Lower CI	Upper CI
Herd 4 (n = 71)				
Non-Forest	0.02	0.07	0.00	0.15
Water	0.07	0.06	0.00	0.13
Seral Stage 0 – 9 years	0.28	0.54	0.38	0.69
Seral Stage 10 – 21 years	0.04	0.01	0.00	0.05
Seral Stage > 21 years	0.59	0.32	0.18	0.47
Herd 5 (n = 56)				
Non-Forest	0.03	0.12	0.00	0.21
Water	0.08	0.05	0.00	0.13
Seral Stage 0 – 9 years	0.11	0.05	0.00	0.13
Seral Stage 10 – 21 years	0.26	0.43	0.26	0.60
Seral Stage > 21 years	0.52	0.52	0.19	0.52
Herd 6 (n = 60)				
Non-Forest	0.03	0.12	0.01	0.22
Water	0.04	0.07	0.00	0.15
Seral Stage 0 – 9 years	0.27	0.43	0.27	0.60
Seral Stage 10 – 21 years	0.04	0.02	0.00	0.06
Seral Stage > 21 years	0.62	0.37	0.21	0.53
Herd 7		Omitted from analysis		

Appendix F. Simultaneous confidence intervals using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the habitat use of female Roosevelt elk herds (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. (continued)

			Confidence Interval Lower ≤ p_i ≤ Upper	
Habitat Type	Expected	Actual (p_i)	Lower CI	Upper CI
Herd 8 (n = 58)				
Non-Forest	0.02	0.10	0.00	0.21
Water	0.08	0.09	0.00	0.18
Seral Stage 0 – 9 years	0.01	0.09	0.00	0.18
Seral Stage 10 – 21 years	0.28	0.323	0.17	0.49
Seral Stage > 21 years	0.61	0.40	0.23	0.56
Herd 9 (n = 73)				
Non-Forest	0.04	0.01	0.00	0.05
Water	0.07	0.21	0.08	0.33
Seral Stage 0 – 9 years	0.189	0.34	0.20	0.49
Seral Stage 10 – 21 years	0.13	0.10	0.01	0.19
Seral Stage > 21 years	0.58	0.34	0.20	0.49
Herd 10 (n = 50)				
Non-Forest	0.01	0.02	0.00	0.07
Water	0.05	0.16	0.03	0.29
Seral Stage 0 – 9 years	0.42	0.46	0.28	0.64
Seral Stage 10 – 21 years	0.11	0.14	0.00	0.27
Seral Stage > 21 years	0.41	0.22	0.07	0.37

Appendix G. Habitat use of female Roosevelt elk herds based upon availability using a chi-square goodness-of-fit test and Bonferroni inequality test. Habitat use was examined at the herd level (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. Observed proportion of use was either less than (-), greater than (+), or not significantly different (=) from the expected proportion of use.

				Habitat Type				
Herd	χ^2Stat.	*DF*	*P*	Non Forest	Water	Seral Stage 0 – 9 years	Seral Stage 10 – 21 years	Seral Stage > 21 years
Herd 1	47.44	4	< 0.01[a]	=	+	=	=	=
Herd 2	39.37	4	< 0.01[a]	=	=	+	=	=
Herd 3	8.00	4	0.09	=	=	=	=	=
Herd 4	33.17	4	< 0.01[a]	=	=	+	=	–
Herd 5	25.60	4	< 0.01[a]	=	=	=	=	–
Herd 6	32.18	4	< 0.01[a]	=	=	=	=	–
Herd 7[b]					Omitted from analysis			
Herd 8	50.72	4	< 0.01[a]	=	=	=	=	–
Herd 9	38.91	4	< 0.01[a]	=	+	+	=	–
Herd 10	16.18	4	< 0.01[a]	=	=	=	=	–

[a] Denotes a difference at the 0.05 level of significance when testing all habitats simultaneously.
[b] Herd 7 omitted due to lack of data.

Appendix H. Simultaneous confidence intervals over the duration of the study, biological seasons, and pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the habitat use of female Roosevelt elk herds at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Habitat Type	Expected	Actual (p_i)	Lower CI	Upper CI
Duration (n = 553)				
Non-Forest	0.02	0.08	0.05	0.11
Water	0.04	0.12	0.08	0.15
Seral Stage 0 – 9 years	0.18	0.25	0.20	0.30
Seral Stage 10 – 21 years	0.16	0.16	0.12	0.20
Seral Stage > 21 years	0.60	0.39	0.34	0.45
Calving (n = 97)				
Non-Forest	0.02	0.08	0.01	0.16
Water	0.03	0.13	0.05	0.22
Seral Stage 0 – 9 years	0.13	0.38	0.25	0.51
Seral Stage 10 – 21 years	0.11	0.11	0.03	0.20
Seral Stage > 21 years	0.71	0.29	0.17	0.41
Summer (n = 110)				
Non-Forest	0.02	0.07	0.01	0.14
Water	0.04	0.13	0.05	0.21
Seral Stage 0 – 9 years	0.19	0.26	0.15	0.36
Seral Stage 10 – 21 years	0.16	0.17	0.08	0.26
Seral Stage > 21 years	0.60	0.37	0.25	0.49

Appendix H. Simultaneous confidence intervals over the duration of the study, biological seasons, and pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the habitat use of female Roosevelt elk herds at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. (continued)

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Habitat Type	Expected	Actual (p_i)	Lower CI	Upper CI
Rut (n = 109)				
Non-Forest	0.02	0.06	0.00	0.13
Water	0.04	0.08	0.02	0.15
Seral Stage 0 – 9 years	0.17	0.21	0.11	0.31
Seral Stage 10 – 21 years	0.15	0.17	0.08	0.27
Seral Stage > 21 years	0.63	0.47	0.35	0.59
Fall (n = 144)				
Non-Forest	0.02	0.07	0.02	0.12
Water	0.04	0.13	0.05	0.20
Seral Stage 0 – 9 years	0.16	0.18	0.10	0.26
Seral Stage 10 – 21 years	0.16	0.17	0.09	0.26
Seral Stage > 21 years	0.63	0.45	0.34	0.56
Pre Hunt (n = 332)				
Non-Forest	0.02	0.05	0.02	0.08
Water	0.04	0.13	0.08	0.17
Seral Stage 0 – 9 years	0.20	0.29	0.23	0.36
Seral Stage 10 – 21 years	0.17	0.14	0.09	0.19
Seral Stage > 21 years	0.58	0.39	0.32	0.46

Appendix H. Simultaneous confidence intervals over the duration of the study, biological seasons, and pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the habitat use of female Roosevelt elk herds at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. (continued)

			Confidence Interval Lower ≤ p_i ≤ Upper	
Habitat Type	Expected	Actual (p_i)	Lower CI	Upper CI
Hunt (n = 225)				
Non-Forest	0.02	0.06	0.02	0.10
Water	0.04	0.10	0.05	0.15
Seral Stage 0 – 9 years	0.16	0.18	0.12	0.25
Seral Stage 10 – 21 years	0.16	0.18	0.11	0.24
Seral Stage > 21 years	0.63	0.48	0.39	0.57

[a]n = number of radio-locations for all elk herds combined.

Appendix I. Habitat use of female Roosevelt elk herds over the duration of the study, biological seasons, and pre-hunt and hunt periods based upon availability using a chi-square goodness-of-fit test and Bonferroni inequality test. Data were combined for all 10 elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. Observed proportion of use was either less than (-), greater than (+), or not significantly different (=) from the expected proportion of use.

				Habitat Type				
Season	χ^2 Stat.	*DF*	*P*	Non Forest	Water	Seral Stage 0 – 9 years	Seral Stage 10 – 21 years	Seral Stage > 21 years
Duration	253.53	4	< 0.01[a]	+	+	+	=	–
Calving	19.53	4	< 0.01[a]	=	+	+	=	–
Summer	31.96	4	< 0.01[a]	=	+	=	=	–
Rut	25.35	4	< 0.01[a]	=	=	=	=	–
Fall	39.02	4	< 0.01[a]	=	+	=	=	–
Pre-Hunt	67.72	4	< 0.01[a]	=	+	+	=	–
Hunt	34.74	4	< 0.01[a]	=	+	=	=	=

[a] Denotes a difference at the 0.05 level of significance when testing all habitats simultaneously.

Appendix J. Simultaneous confidence intervals using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use of successive distances from water by female Roosevelt elk herds (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Water Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Herd 1 (n = 67)				
< 50	0.15	0.43	0.27	0.59
51 - 100	0.06	0.08	0.00	0.16
101 - 200	0.11	0.16	0.05	0.28
201 - 400	0.20	0.18	0.06	0.30
401 - 600	0.17	0.03	0.00	0.09
> 600	0.32	0.12	0.02	0.22
Herd 2 (n = 56)				
< 50	0.17	0.23	0.08	0.38
51 - 100	0.10	0.20	0.06	0.34
101 - 200	0.18	0.14	0.02	0.27
201 - 400	0.27	0.16	0.03	0.29
401 - 600	0.15	0.07	0.00	0.16
> 600	0.12	0.20	0.06	0.34
Herd 3 (n = 50)				
< 50	0.13	0.16	0.02	0.30
51 - 100	0.09	0.12	0.00	0.24
101 - 200	0.17	0.20	0.05	0.35
201 - 400	0.28	0.24	0.08	0.40

Appendix J. Simultaneous confidence intervals using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use successive distances from water by female Roosevelt elk herds (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County,Washington from May to November 2000. (continued)

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Water Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
401 - 600	0.20	0.16	0.02	0.30
> 600	0.14	0.12	0.00	0.24
Herd 4 (n = 71)				
< 50	0.12	0.18	0.06	0.30
51 - 100	0.08	0.10	0.01	0.19
101 - 200	0.13	0.14	0.03	0.25
201 - 400	0.22	0.13	0.02	0.23
401 - 600	0.18	0.14	0.03	0.25
> 600	0.29	0.31	0.17	0.46
Herd 5 (n = 56)				
< 50	0.06	0.07	0.00	0.16
51 - 100	0.04	0.02	0.00	0.07
101 - 200	0.08	0.05	0.00	0.13
201 - 400	0.15	0.25	0.10	0.40
401 - 600	0.16	0.11	0.00	0.22
> 600	0.52	0.50	0.32	0.67

Appendix J. Simultaneous confidence intervals using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use successive distances from water by female Roosevelt elk herds (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County,Washington from May to November 2000. (continued)

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Water Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Herd 6 (n = 60)				
< 50	0.13	0.13	0.02	0.25
51 - 100	0.08	0.12	0.01	0.23
101 - 200	0.14	0.20	0.06	0.34
201 - 400	0.23	0.25	0.10	0.40
401 - 600	0.18	0.08	0.00	0.18
> 600	0.25	0.22	0.08	0.36
Herd 7		Omitted from analysis		
Herd 8 (n = 58)				
< 50	0.16	0.21	0.07	0.35
51 - 100	0.09	0.14	0.02	0.26
101 - 200	0.17	0.12	0.01	0.23
201 - 400	0.25	0.21	0.07	0.35
401 - 600	0.15	0.16	0.03	0.28
> 600	0.18	0.17	0.04	0.30

Appendix J. Simultaneous confidence intervals using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use successive distances from water by female Roosevelt elk herds (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County,Washington from May to November 2000. (continued)

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Water Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Herd 9 (n = 73)				
< 50	0.19	0.55	0.39	0.70
51 - 100	0.10	0.06	0.00	0.13
101 - 200	0.16	0.10	0.01	0.19
201 - 400	0.23	0.16	0.05	0.28
401 - 600	0.14	0.06	0.00	0.13
> 600	0.18	0.08	0.00	0.17
Herd 10 (n = 51)				
< 50	0.15	0.28	0.11	0.44
51 - 100	0.09	0.16	0.02	0.29
101 - 200	0.16	0.08	0.00	0.18
201 - 400	0.27	0.28	0.11	0.44
401 - 600	0.18	0.12	0.00	0.24
> 600	0.14	0.10	0.00	0.21

Appendix K. Use of successive distances from water by female Roosevelt elk herds based upon availability using a chi-square goodness-of-fit test and Bonferroni inequality test. Use of distance categories was examined at the herd level (95% fixed kernel) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. Observed proportion of use was either less than (-), greater than (+), or not significantly different (=) from the expected proportion of use.

				Distance from Water (m)					
Elk Herd	χ^2 Stat.	*DF*	*P*	< 50	51-100	101-200	201-400	401-600	> 600
Herd 1	55.24	5	< 0.01[a]	+	=	=	=	–	–
Herd 2	14.23	5	0.24	=	=	=	=	=	=
Herd 3	10.65	5	0.90	=	=	=	=	=	=
Herd 4	6.05	5	0.30	=	=	=	=	=	=
Herd 5	6.23	5	0.29	=	=	=	=	=	=
Herd 6	5.72	5	0.34	=	=	=	=	=	=
Herd 7[b]				Omitted from analysis					
Herd 8	3.47	5	0.63	=	=	=	=	=	=
Herd 9	61.07	5	< 0.01[a]	+	=	=	=	–	–
Herd 10	11.16	5	0.07	=	=	=	=	=	=

[a] Denotes a difference at the 0.05 level of significance when testing all habitats simultaneously.
[b] Herd 7 omitted due to lack of data.

Appendix L. Simultaneous confidence intervals over the duration of the study, biological seasons, and pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use of successive distances from water. Data were combined for all 10 female Roosevelt elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Water Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Duration (n = 553)				
< 50	0.12	0.25	0.20	0.30
51 - 100	0.07	0.10	0.07	0.14
101 - 200	0.13	0.13	0.09	0.16
201 - 400	0.22	0.20	0.15	0.24
401 - 600	0.17	0.10	0.07	0.13
> 600	0.30	0.22	0.18	0.27
Calving (n = 97)				
< 50	0.11	0.25	0.13	0.36
51 - 100	0.07	0.10	0.02	0.19
101 - 200	0.12	0.09	0.02	0.17
201 - 400	0.21	0.19	0.08	0.29
401 - 600	0.17	0.13	0.04	0.23
> 600	0.32	0.24	0.12	0.35

Appendix L. Simultaneous confidence intervals over the duration of the study, biological seasons, and pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use of successive distances from water. Data were combined for all 10 female Roosevelt elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. (continued)

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Water Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Summer (n = 110)				
< 50	0.11	0.21	0.11	0.31
51 - 100	0.07	0.08	0.01	0.15
101 - 200	0.12	0.16	0.07	0.26
201 - 400	0.21	0.26	0.15	0.36
401 - 600	0.17	0.09	0.02	0.16
> 600	0.32	0.20	0.10	0.30
Rut (n = 109)				
< 50	0.11	0.28	0.16	0.39
51 - 100	0.07	0.11	0.03	0.19
101 - 200	0.13	0.15	0.06	0.24
201 - 400	0.23	0.21	0.11	0.31
401 - 600	0.17	0.07	0.00	0.14
> 600	0.29	0.18	0.09	0.28

Appendix L. Simultaneous confidence intervals over the duration of the study, biological seasons, and pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use of successive distances from water. Data were combined for all 10 female Roosevelt elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. (continued)

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Water Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Fall (n = 145)				
< 50	0.11	0.26	0.16	0.35
51 - 100	0.07	0.12	0.05	0.20
101 - 200	0.13	0.15	0.07	0.23
201 - 400	0.22	0.21	0.12	0.30
401 - 600	0.17	0.10	0.03	0.16
> 600	0.29	0.17	0.08	0.25
Pre-Hunt (n = 332)				
< 50	0.12	0.24	0.18	0.31
51 - 100	0.07	0.10	0.06	0.15
101 - 200	0.13	0.12	0.07	0.17
201 - 400	0.22	0.18	0.13	0.24
401 - 600	0.17	0.11	0.06	0.15
> 600	0.31	0.24	0.18	0.30

Appendix L. Simultaneous confidence intervals over the duration of the study, biological seasons, and pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use of successive distances from water. Data were combined for all 10 female Roosevelt elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. (continued)

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Water Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Hunt (n = 225)				
< 50	0.12	0.27	0.19	0.35
51 - 100	0.07	0.12	0.06	0.17
101 - 200	0.13	0.15	0.08	0.21
201 - 400	0.23	0.21	0.14	0.29
401 - 600	0.17	0.08	0.04	0.13
> 600	0.29	0.17	0.10	0.24

Appendix M. Use of successive distances from water by female Roosevelt elk herds over the duration of the study, biological seasons, and pre-hunt and hunt periods based upon availability using a chi-square goodness-of-fit test and Bonferroni inequality test. Data were combined for all 10 Roosevelt elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. Observed proportion of use was either less than (-), greater than (+), or not significantly different (=) from the expected proportion of use.

				Water Class (m)					
Season	χ^2 Stat.	*DF*	*P*	< 50	51-100	101-200	201-400	401-600	> 600
Duration	124.56	5	< 0.01[a]	+	=	=	=	–	–
Calving	23.21	5	< 0.01[a]	+	=	=	=	=	=
Summer	21.08	5	< 0.01[a]	=	=	=	=	–	–
Rut	38.35	5	< 0.01[a]	+	=	=	=	–	–
Fall	44.34	5	< 0.01[a]	+	=	=	=	–	–
Pre-Hunt	71.28	5	< 0.01[a]	+	=	=	=	–	–
Hunt	71.33	5	< 0.01[a]	+	=	=	=	–	–

[a] Denotes a difference at the 0.05 level of significance when testing all habitats simultaneously.

Appendix N. Simultaneous confidence intervals over the duration of the study and during pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use of successive distances from primary roads. Data were combined for all 10 Roosevelt elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Primary Road Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Duration (n = 553)				
0 - 100	0.14	0.16	0.12	0.20
101 - 200	0.13	0.15	0.11	0.18
201 - 400	0.24	0.24	0.20	0.29
> 400	0.49	0.45	0.40	0.51
Pre-Hunt (n = 332)				
0 - 100	0.12	0.15	0.10	0.19
101 - 200	0.12	0.13	0.08	0.18
201 - 400	0.21	0.24	0.18	0.29
> 400	0.55	0.49	0.42	0.56
Hunt (n = 225)				
0 - 100	0.47	0.18	0.12	0.25
101 - 200	0.29	0.17	0.11	0.24
201 - 400	0.17	0.24	0.17	0.31
> 400	0.07	0.41	0.33	0.49

Appendix O. Simultaneous confidence intervals over the duration of the study and during pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use of successive distances from secondary roads. Data were combined for all 10 Roosevelt elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Secondary Road Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Duration (n = 553)				
0 - 100	0.47	0.26	0.21	0.30
101 - 200	0.29	0.41	0.36	0.47
201 - 400	0.18	0.26	0.21	0.30
> 400	0.07	0.08	0.05	0.10
Pre-Hunt (n = 332)				
0 - 100	0.46	0.27	0.21	0.33
101 - 200	0.29	0.40	0.33	0.47
201 - 400	0.18	0.26	0.20	0.32
> 400	0.07	0.08	0.04	0.11
Hunt (n = 225)				
0 - 100	0.47	0.24	0.17	0.32
101 - 200	0.29	0.43	0.35	0.51
201 - 400	0.17	0.25	0.18	0.32
> 400	0.07	0.08	0.03	0.12

Appendix P. Simultaneous confidence intervals over the duration of the study and during pre-hunt and hunt periods using a chi-square goodness-of-fit test and Bonferroni inequality test to assess the use of successive distances from paved roads. Data were combined for all 10 Roosevelt elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000.

			Confidence Interval Lower $\leq p_i \leq$ Upper	
Paved Road Class (m)	Expected	Actual (p_i)	Lower CI	Upper CI
Duration (n = 553)				
< 600	0.08	0.10	0.07	0.13
> 600	0.92	0.90	0.87	0.93
Pre-Hunt (n = 332)				
< 600	0.11	0.15	0.12	0.20
> 600	0.89	0.85	0.81	0.89
Hunt (n = 225)				
< 600	0.06	0.03	0.01	0.05
> 600	0.94	0.97	0.95	0.99

Appendix Q. Use of successive distances from roads by female Roosevelt elk herds over the duration of the study and during pre-hunt and hunt periods based upon availability using a chi-square goodness-of-fit test and Bonferroni inequality test. Data were combined for all 10 elk herds and analyzed at the population level (MCP) on the Hoko and Dickey game management units, Clallam County, Washington from May to November 2000. Observed proportion of use was either less than (-), greater than (+), or not significantly different (=) from the expected proportion of use.

					Distance from Road Type (m)			
Road Type	Season	χ^2 Stat.	*DF*	*P*	0-100	101-200	201-400	> 400
Primary								
	Duration	4.68	3	0.20	=	=	=	=
	Pre-Hunt	4.19	3	0.24	=	=	=	=
	Hunt	415.10	3	< 0.01[a]	–	–	=	+
Secondary								
	Duration	103.83	3	< 0.01[a]	–	+	+	=
	Pre-Hunt	55.04	3	< 0.01[a]	–	+	+	=
	Hunt	49.22	3	< 0.01[a]	–	+	+	=
Paved					< 600		> 600	
	Duration	4.59	1	0.07	=		=	
	Pre-Hunt	6.07	1	0.10	=		=	
	Hunt	3.21	1	0.04	–		+	

[a] Denotes a difference at the 0.05 level of significance when testing all habitats simultaneously.