EFFECT OF HAIR LOSS SYNDROME ON SURVIVAL, BEHAVIOR AND HABITAT SELECTION OF BLACK-TAILED DEER FAWNS

By

Shannon L. Murphie

A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

In Natural Resources: Wildlife

August 2010

ABSTRACT

EFFECT OF HAIR LOSS SYNDROME ON SURVIVAL, BEHAVIOR AND HABITAT SELECTION OF BLACK-TAILED DEER FAWNS

Shannon L. Murphie

Black-tailed deer (*Odocoileus hemionus columbianus*) of Washington State have existed with hair loss syndrome (HLS) since 1996. I looked at the effects of HLS on individual fawns by estimating survival rates, time budgets associated with feeding and scratching behaviors and important environmental characteristics at the microhabitat and microclimate scale. A total of 166 fawns were captured between 2006 and 2008. Survival did not differ between years resulting in an average annual survival rate of 0.37, with early survival (from estimated date of birth through nine weeks) of 0.71 and winter survival (1 Dec through 1 Mar) of 0.64. Survival rates were higher among non-hair-loss (NHLS) than HLS fawns. Predation was the primary, proximate source of mortality, with cougars (*Puma concolor*) being the most significant predator. Poor nutritional condition over the winter likely influenced mortality, given that 89% of fawns that died from predation also showed moderate to severe nutritional stress, based on examination of bone marrow. Fawns with HLS spent a greater proportion of time scratching and a reduced proportion of time feeding compared to NHLS fawns. The tradeoff between increased scratching and reduced feeding contributed to lower body condition indices and higher rates of nutritional stress in HLS fawns. Deer selected habitats with higher microclimate temperatures, greater canopy cover and lower mean shrub density

compared to random sites. This supports the use of microhabitat and microclimate as a trade-off between forage quality and quantity, hiding cover from predators, and a need for increased thermal cover in the winter. I conclude that increased scratching among HLS fawns results in a reduction of time spent feeding, subsequently lowering body condition and over-winter survival.

ACKNOWLEDEMENTS

I thank Dr. Micaela Szykman Gunther for serving as my major advisor and providing guidance throughout this project; and my committee members, Drs. Richard Golightly and Richard Brown for their comments on this document.

I would like to extend my deepest gratitude to two of the most integral people throughout this research, Rob McCoy and Bryan Murphie, who have taught me more than they know. I thank Rob McCoy, Makah Wildlife Manager, for allowing me to be a part of this research and supporting every aspect of this project. I thank Bryan Murphie for believing in me and supporting me, for the sacrifices he has made, countless hours of field assistance and the many initial reviews of this document. Also, for his patience, dedication and knowledge, I am grateful.

The Washington Chapter of the Mule Deer Foundation, Marin Rod and Gun Club, Stockton Sportsman's Club, KBH Archers through a Washington State ALEA grant, Humboldt State University, Makah Tribal Council, and Unresolved Fishing and Hunting Rights Program through the Bureau of Indian Affairs provided funding, without which this project would not have been possible.

Thank you to Bob Conrad and Marianna Alexandersdottir of the Northwest Indian Fisheries Commission, and to Alissa Fogg for statistical help. Jon Gallie, wildlife biologist, and Jeremiah Johnson, Tony Pascua, John Neuneker, and Leroy Dalos, Makah Tribe technicians that assisted with many aspects of data collection and captures, thank you for all your hard work. Additional support for captures was provided by the

following: KBH Archers, especially Tal Dobbs, Gene Schanzmeyer, Dan Siegner, and Bob Welch; Daniel Ravenel of the Quinault Indian Nation; Chris Madsen of the Northwest Indian Fisheries Commission; Bryan Murphie of the Washington Department of Fish and Wildlife (WDFW); WDFW Advanced Hunter Volunteers, especially Bill Brown; and Kim Sager-Fradkin and Brandon Nickerson from the Lower Elwha Tribe.

I thank Green Crow, GMO (Grantham, Mayo, VanOtterloo) Renewable Resources LLC, Eco Trust and Makah Forestry Enterprise for providing access to the study area and supporting the research work of the Makah Tribe.

Anthony Desch from the HSU stockroom and Dr. Jeff Black's lab provided extended use of equipment, a special thank you to Lindsy Green and Chris West for advice on equipment and use of associated software.

Finally, I would like to thank my friends and colleagues that made my time at Humboldt State enjoyable, including my lab mates Jennifer Terry and Kristin Brzeski, especially for running paperwork around for me, and Marlene Wagner, for making me laugh when I needed it most. To my family and friends, thank you for your advice and encouragement over the years.

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INTRODUCTION

Infestations of *Damalinia* (*Cervicola*) *sp*., an exotic species of biting louse, have resulted in a hair loss syndrome (HLS) that may have long-term impacts on Columbian black-tailed deer (*Odocoileus hemionus columbianus*) populations. HLS was first observed in Washington State (USA) in 1996 (Bender and Hall 2004). It spread throughout western Washington and into Oregon by 1998 (Bildfell et al. 2004) and has recently (2004) been confirmed in northern California, south to Mendocino County (D. Lancaster, California Department of Fish and Game, personal communication). Clinical signs of HLS are a loss of pelage over the ribcage, flanks and hind quarters, along with emaciation and lethargy in late fall through winter and into early spring (Bender and Hall 2004; Bildfell et al. 2004). These signs are most common in fawns but do occur in other age classes. Robison (2007) identified a link between irritation of HLS, grooming response and the loss of hair. Initial signs appear as a darkening in coat color, then thinning of the hair coat on both sides results as animals groom and rub infected areas excessively, leading to yellow or white coloration from hyper-pigmentation and hyperkeratosis of the skin (Bender and Hall 2004). In severe cases, HLS results in bald patches of skin, animals become progressively weaker and lethargic leading into emaciation; ultimately hypothermia and malnutrition may result in death (Bender and Hall 2004; Bildfell et al. 2004).

Anecdotal evidence indicates that deer harvest has declined in some game management units affected by HLS since the onset in 1996 (Bender and Hall 2004; R.

McCoy, Makah Forestry, personal communication), and there may be considerable effects on deer populations through increased over-winter fawn mortality or depressed doe productivity (Washington Department of Fish and Wildlife 2007). Factors affecting these populations, including the influence of HLS, may impact future harvest levels.

Short-term effects of this infestation on black-tailed deer populations did not increase over-winter mortality of fawns or decrease fawn production or recruitment (Bender and Hall 2004). However, Bender and Hall (2004) only examined fawn-to-doe ratios over the short-term using the ratios as an index, which did not measure effects on individuals. Fawn mortality due to HLS has not been directly addressed and studies of the long-term effects have yet to be conducted. Bender and Hall (2004) did report apparent declining populations in six of eight Game Management Units.

Black-tailed deer fawn research was initiated by the Makah Tribe in 2006, 1) to determine age-specific survival rates, sources of mortality and other factors that may be limiting survival of fawns; 2) to investigate the effects HLS has on individual fawn survival; and 3) to obtain a better understanding of the influence that fawn survival and mortality have on the population rate of change (McCoy 2008). My study represented a component of the tribe's research of the impacts of HLS on individual fawn survival and behavior.

Juvenile deer survival plays a larger role in population dynamics than survival of adults (Gaillard et al. 1998). Fawns were chosen for study because of their high vulnerability to mortality from multiple sources (Carroll and Brown 1977, Whittaker and Lindzey 1999, Gilbert and Raedeke 2004, Vreeland et al. 2004, Lomas and Bender 2007,

Rohm et al. 2007) and greater mortality rates over the winter compared to adults (Parker et al. 1999; Taillon et al. 2006). Fawns also experience higher incidence rates of HLS (Bender and Hall 2004) and they were expected to suffer greater consequences associated with heavy parasite loads and HLS than adults.

Typically, the cost of lice infestations is considered minor for ungulates (Mooring et al. 2004a). However, with the recent (1996) invasion of the non-native louse *Damalinia (Cervicola) sp*., deer have not developed an immune response. Limited defense against this louse may lead to increased susceptibility to secondary effects such as reduced fitness, diseases and further increased parasite loads. Additionally, the heaviest louse infestations occur during the winter. Considering that black-tailed deer experience winter forage conditions that rarely meet energy requirements (Parker et al. 1999), increased parasite loads during this time could potentially exacerbate the effect of winter stress similar to that seen in moose (*Alces alces*) populations (DelGiudice et al. 1997; Murray et al. 2006).

Mooring et al. (1996) and Mooring and Samuel (1998) found that animals with high parasite loads groomed more than those without ectoparasites, following a stimulus-driven mechanism typical of naïve hosts. Increased grooming behavior was associated with costs including a reduction in time spent foraging (Yamada and Urabe 2007), decreased vigilance against predators (Mooring and Hart 1995), and loss of hair, resulting in increased thermoregulatory costs (Mooring and Samuel 1999). Bildfell et al. (2004) and Foreyt et al. (2004) found that deer with HLS had lower body weights and appeared to be in poorer condition compared to deer without HLS. Bildfell et al. (2004) suggested

that this reduction in condition and weight might be related to a decrease in feeding time. If HLS deer spend less time feeding or being vigilant, these factors may be impacting their survival.

I hypothesized that HLS would influence fawn behavior and survival. Deer that develop HLS must compensate for the increase in thermoregulation and energy stress either by consuming more food or taking advantage of thermal cover. I predicted that fawns with HLS would spend more time scratching than fawns without HLS, which would result in a reduction of time spent foraging and being vigilant. Fawns with HLS that did not compensate by consuming more energy or reducing energy costs should experience a higher rate of mortality than fawns without HLS, and susceptibility to mortality (probably through predation) was expected to increase with the prevalence of HLS.

In some studies, forage, nutritional demands and climate were more important to deer in their selection of habitat than risk of predation (Bowyer et al. 1998; Ratikainen et al. 2007). Deer may put themselves at greater risk of predation to improve their foraging opportunities. Deer with HLS may also require different microclimates in order to mitigate heat loss through loss of pelage, similar to moose affected by the winter tick (*Dermacentor albipictus*, Mooring and Samuel 1999). Thus, I predicted that deer with HLS would use habitats differently than deer without HLS, especially during winter months.

Robison (2007) indicated a need for additional information regarding susceptibility to louse infestation such as body condition, immunity, age, nutrition and

gender. Blood chemistry has shown some utility as an index to relative condition (Bishop et al. 2009a) and may be useful in determining predisposition of fawns to louse infestation. Fitness is influenced by nutrition, directly related to dietary protein and energy of an animal's diet (Seal et al. 1978, Brown et al. 1995) and can be predicted by using blood serum indices (Seal et al. 1978, Anderson 1981, Bishop et al. 2009a). My final objective assessed at-birth and at-capture condition of fawns through morphology and blood chemistry analysis to determine if HLS onset, poor condition in winter and ultimately mortality were correlated with poor fawn condition in the spring.

STUDY AREA

My research was conducted in the Hoko Game Management Unit (GMU) located in the northwest corner of the Olympic Peninsula, Clallam County, Washington, USA (Figure 1). The Hoko GMU is approximately 233 km^2 and is bounded to the north by the Makah Reservation and to the northeast by the Straight of Juan de Fuca between the northeast corner of the Makah Reservation and the mouth of the Hoko River, to the east, southeast and south by the Hoko-Ozette Road, and to the west by Olympic National Park between Ozette and the Makah Reservation.

The majority of the lands within the Hoko GMU are privately owned timberlands that are harvested on a 50-year rotational basis. The Washington Department of Natural Resources also manages a small amount of public timberland throughout the study area. Intensive timber harvest has converted old-growth forests to second and third growth stand conditions ranging from grass forbs following clear cutting to closed sapling-pole saw timber (Hall et al. 1985, McCoy 2008). Stand conditions are largely dominated by younger age clear cuts as the area has been subject to significant timber harvest over the past 10 years (McCoy 2008). Roads accessing timberlands along Hwy 112 and the Hoko-Ozette Road have been gated since 1987. Entry is limited to non-motorized transportation for all recreational and hunting activities. A minor amount of land within the Hoko GMU is developed either as small residential areas, isolated homes, or small ranching operations (primarily as fenced pastureland) located along Hwy 112 and the Hoko-Ozette Road.

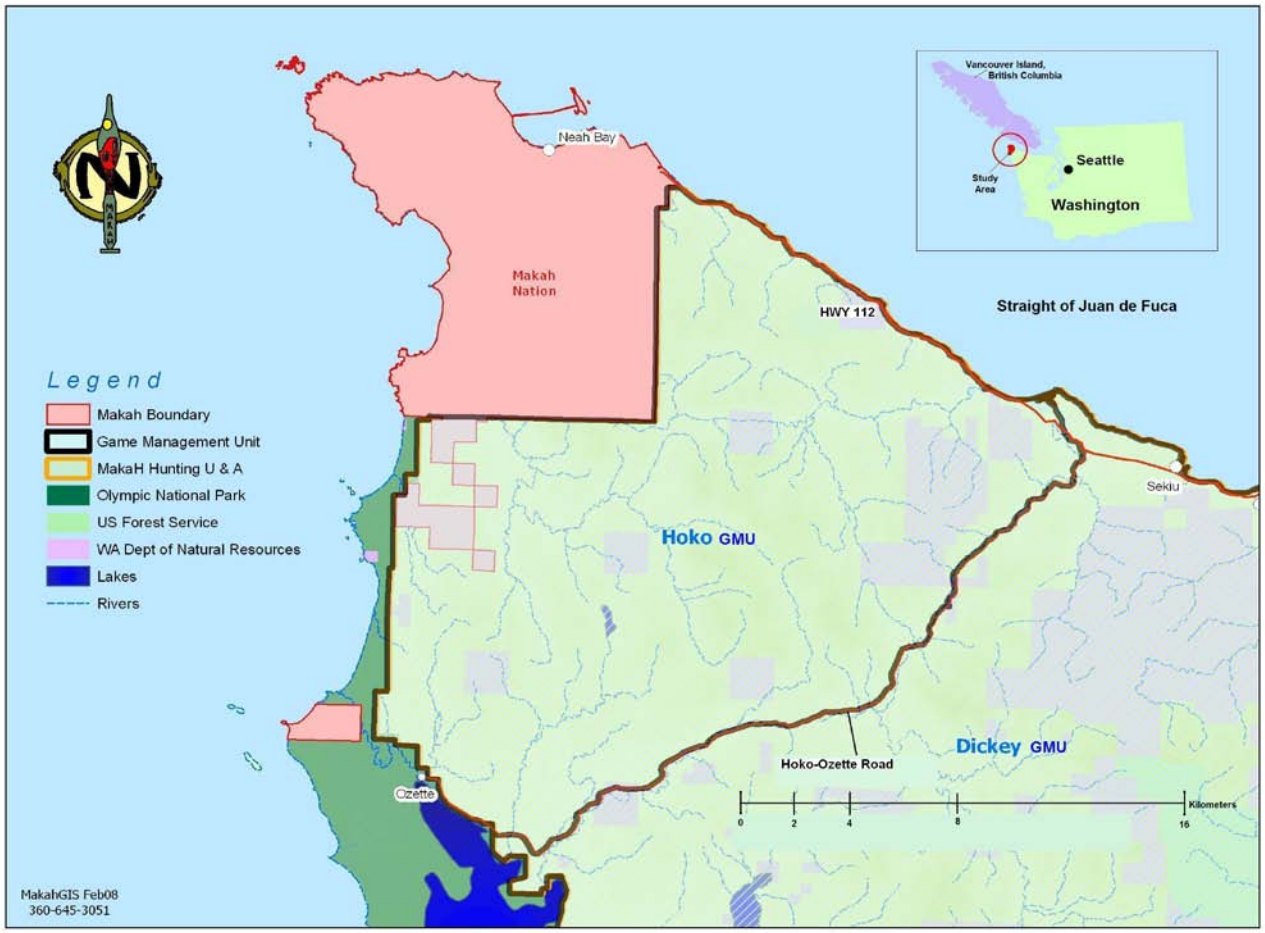


Figure 1. Study area location of black-tailed deer hair loss syndrome research within the Hoko Game Management Unit, Washington, USA, 2006-2009. Map inset shows the study area in relationship to Washington State and Vancouver Island, British Columbia.

Elevations within the Hoko GMU extend from sea level to just over 600 m at ridge tops. Climate is characterized by warm dry summers and cool, wet winters typical of maritime influences. Annual temperatures are mild and average from 3-12^{o}C in January and 10-19^{o}C in August. Precipitation averages 254 cm mostly occurring as rain from October to March, with snow occurring occasionally at higher elevations. When westerly winds are disrupted between December and February, a small accumulation of snow occurs in the lowlands, rarely exceeding 8 cm and typically lasting only a few days (McCoy 2008). Winter storms are commonly accompanied by severe winds that routinely exceed 64 km per hour at the coast and can reach 80 to 96 km per hour in mountain valleys (McCoy 2008).

The northern Olympic Peninsula is dominated by temperate coniferous forests and is characterized by the *Picea sitchensis* (Sitka spruce) zone. Dominant tree species include Sitka spruce, western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*), pacific silver fir (*Abies amabilis*), and western red cedar (*Thuja plicata*). Riparian tree species include red alder (*Alnus rubra*), big-leaf maple (*Acer macrophillum*) and black cottonwood (*Populus trichocarpa*). Major understory species include vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), salmonberry (*Rubus spectabillis*), red huckleberry (*Vaccinium parvifolium*), thimbleberry (*Rubus parviflorus*), devil's club (*Oplopanax horridus*), red elderberry (*Sambucus recemosa*), swordfern (*Polystichum munitum*), lady fern (*Athyrium filix-femina*), deer fern (*Belchnum spicant*), vanilla leaf (*Achlys triphylla*), trillium (*Trillium ovatum*), Oregon oxalis (*Oxalis oregano*), and Oregon grape (*Berberis nervosa*, Franklin and Dyrness 1988, Makah Forestry 1999).

METHODS

Fawn Capture and Processing

Black-tailed deer fawns of both sexes were captured between 20 May and 11 June over three years (2006-2008). Teams of 2-4 people drove vehicles along roads searching for fawns or does displaying maternal behaviors such as searching, nursing, aggression toward other adult deer and careful visual monitoring of specific sites (Downing and McGinness 1969, White et al. 1972, Ozoga et al. 1982, Heister 1985). A fawn bleat call (Diem 1954, Arthur et al. 1978) was used occasionally to elicit behavioral responses from does that may have a fawn nearby. Once fawns or does were observed, teams conducted foot searches methodically so that entire areas were completely covered. When fawn tracks were found, an increased search effort was concentrated to the surrounding area.

Fawns were captured by hand with the aid of salmon landing nets to prevent escape (0.9 m hoop diameter, 1.2 m handles; Lund 1975). Transfer of human scent was minimized by limiting handling time and wearing latex gloves that were discarded after each captured fawn. Scent transfer to the fawn bed site was minimized by processing fawns >10 m from the capture site, where only one person retrieved and returned the fawn immediately after processing (approximately 15-20 min). Polypropylene sacks used to weigh fawns were used only once until washed to remove ectoparasites and scent.

Capture crews recorded the sex of each fawn, and measured total curvilinear length, girth circumference, hind foot length, and femur length to the nearest 0.1 cm. A standardized sternal body position was used to measure curvilinear length from the tip of

the nose to the base of the tail. New growth of the hind hoof was measured to the nearest 0.1 mm (Haugen and Speake 1958) using dial calipers (31-415-3, Forestry Suppliers Inc., Jackson, Mississippi). A 10 kg Pesola scale (AAS/Pesola, Kapuskasing, Ontario, Canada) and a polypropylene sack were used to weigh fawns to the nearest 0.1 kg. Approximately 8 ml of whole blood was drawn, collected in serum separator tubes, and kept cool until centrifuged within 8 hrs. Serum samples were stored frozen until submission to Michigan State University, Diagnostic Center for Population and Animal Health, for serum chemistry, thyroid and insulin-like growth hormone analysis. Each fawn had a transmitter (148-151 MHz) attached to an elastic expandable radio collar (M4210, Advanced Telemetry Systems, Inc., Insanti, Minnesota, or MOD-205/CB-4, Telonics, Inc., Mesa, Arizona). Radio collars weighed 68 g, less than 3% total body mass at birth (Cowan and Wood 1955). Transmitters were equipped with a mortality mode that initiated after 6 hrs without movement.

All methods were approved by the Humboldt State University Institutional Animal Care and Use Committee (IACUC Protocol No. 07/08.W.15.A). All statistical tests were analyzed using program R (version 2.8.1, Free Software Foundation, Inc., Boston, Massachusetts) unless otherwise stated. I considered all statistical analyses significant at $\alpha = 0.05$ level and means are presented ±1 SE.

Hair Loss Syndrome Criteria

I considered fawns to be HLS fawns if they exhibited external clinical signs, including a white to orange discoloration of the hair coat, loss of hair, especially broken

guard hairs over ribcage, flanks, hind quarters or neck, or upon recovery of a fawn carcass with a heavy infestation of lice ($\geq$ 35 lice/cm^2 on multiple locations of the body; Bildfell et al. 2004). Heavy louse infestations or loss of hair following the pattern of HLS of all fawns were assumed to be caused by the exotic louse *Damalinia (Cervicola) sp*. For confirmation, five vials containing multiple lice were sampled from fawn carcasses and submitted to the US Department of Agriculture, Animal and Plant Health Inspection Service (National Veterinary Services Laboratory, Ames, Iowa) for positive identification. All lice were confirmed as the undetermined species of *Damalinia* (*Cervicola*) found on deer with HLS.

Mortality and Survival

I monitored radio-collared deer from date of capture (May/June) until mortality or project completion. I monitored radio-collared fawns for survival once daily, seven days per week through August, then five times weekly from January through May in 2008 and 2009. Fawns were monitored by Makah Tribal staff from September through December. I used a Omni directional vehicle-mounted antenna or hand held antenna (RA-5A or RA-14 H, Telonics Inc., Mesa, Arizona) and portable receiver (R1000, Communications Specialists, Inc., Orange, California).

I conducted field investigations to determine causes of mortality as soon as possible after receiving a mortality signal. At mortality sites, I documented physical evidence, took photographs of the site and carcass, and collected lice and carcass remains, if present. If fawns were intact, the entire carcass was collected for submission

to the Washington State University Animal Diagnostic Laboratory (Pullman, Washington) or the United States Geological Survey (USGS) National Wildlife Health Center (Madison, Wisconsin) for necropsy. When entire fawns could not be collected, a field necropsy was performed and organ samples were frozen for submission to the USGS National Wildlife Health Center.

Assignment of cause of mortality included predation, non-predation natural, human related and unknown. Capture-related mortalities occurred within 24 hours of capture activities and were determined upon examination and subsequently censored from survival analysis. When predation was the suspected cause of death, I attempted to identify specific predators including black bear (*Ursus americanus*), bobcat (*Lynx rufus*), and coyote (*Canis latrans*) based on a modified key by Vreeland (2002), and cougar (*Puma concolor*) as described by Hayes et al. (2000). Specific details regarding mortality assessment (Appendix A) were based on definitive evidence from this study and may not be indicative of mortality events recorded in other locations or localized predator characteristics. Non-predation natural mortalities were broken down into nutritional stress and HLS influenced. I assessed nutritional stress from examination of bone marrow, where red, gelatinous marrow indicated severe malnutrition, pink and gelatinous or red and partially pasty indicated moderate malnutrition, and white or pink and pasty indicated little to no malnutrition (Riney 1955, Takatsuki 2001). Additionally, fawns submitted for necropsy that were emaciated were also included in the nutritionally stressed category. I identified HLS-influenced mortalities by condition of the carcass

including loss of guard hairs, emaciation or nutritional stress, and presence of multiple lice attached to the hide.

Mortality and Survival Data Analysis

Survival was analyzed to determine whether a peak in mortality occurred during the early time period, the HLS time period, or both. The early time interval was defined as the first nine weeks of life from the estimated date of birth, and the HLS time interval was defined as 1 December to 1 March. The known fates model in Program MARK version 5.1 (White 2008) was used to estimate fawn survival and investigate covariates influencing survival. Fawns with collars that failed or broke off early were censored from survival analysis. These animals provided data up to the time when they were censored. I estimated weekly survival rates and produced survivorship curves of fawns for all years (2006-2009) from estimated dates of birth through recruitment (1 May). I used a set of a priori survival models based on ecologically significant time intervals and individual covariates (Table 1). Variations in time included week and year as well as the interval from birth through the first nine weeks of life and the interval in which fawns are most at risk of HLS during the winter. Models were selected using Akaike Information Criteria corrected for small sample sizes (AICc). The best model selected from model set one was used to test a second set of survival models related to individual covariates including sex, estimated weight at birth, and condition determined from morphology.

I used Program MARK to select the best model from a set of a priori models during the HLS interval. I tested the difference between survival rates of fawns without

HLS (non-HLS or NHLS) and HLS fawns (Table 2), using the best model from this set. A chi-square test of heterogeneity (Zar 1999) was used to determine if the total number of NHLS fawns and HLS fawns surviving and dying was similar between years. Data were pooled for all years and compared using a 1-tailed Fisher's exact test (Zar 1999) to test the null hypothesis that survival of NHLS fawns was not higher than survival of HLS fawns. A 1-tailed Fisher's exact test was used to test whether the predation rate was higher for HLS fawns compared to NHLS fawns.

Behavior

I visually observed fawns 1-2 times monthly, January through April in 2008 and 2009 to quantify foraging, grooming and vigilant behavior. I randomly selected one HLS individual from the pool of collared fawns, which was located and observed using 10x42 binoculars (Wind River, Leupold, Beaverton, Oregon) or 15-45X spotting scope (Spacemaster, Bushnell Corporation, Overland Park, Kansas) for a 20-minute period using focal animal sampling (Altmann 1974). Behaviors were recorded with a handheld computer (Psion Workabout MX, Psion Teklogix, Mississauga, Ontario, Canada), and downloaded for analysis using The Observer 5.0 (2003, Noldus Information Technology, Wageningen, The Netherlands). Following the observation of a HLS fawn, a NHLS fawn was chosen by availability of being located and observed in the same manner. Pairs of HLS and NHLS fawns were created whereby no two individuals were ever paired twice. I rotated through the list of fawns until all possible pairs were obtained or data collection ceased. In 2009, to increase sample size of HLS fawns, I searched the study area for

Table 1. A priori models used to determine variation in time dependence and the influence of individual covariates on overall survival of black-tailed deer fawns in the Hoko Game Management Unit, Washington, USA during 2006-2009. The early time interval includes estimated birth date through the first 9 weeks of life and the HLS time interval is 1 Dec through 1 Mar.

	Model	Number of Parameters	Description
Set 1	$S_{constant}$	1	Survival was constant over all weeks and years
	S_{age}	50	Survival varied by the age (weeks) of fawns
	S_{year}	3	Survival varied among the 3 capture years
	$S_{ageXyear}$	150	Survival varied by age and among capture year
	$S_{age\text{-}2intervals}$	2	Survival varied by age of fawn in 2 stages ($\leq$9 weeks, >9 weeks)
	$S_{age\text{-}2intervalXyear}$	6	Survival varied by age of fawn in 2 stages and among capture year
	$S_{age\text{-}3intervals}$	3	Survival varied by age of fawn in 3 stages (early, HLS, all other weeks combined)
	$S_{age\text{-}3intervalXyear}$	9	Survival varied by age of fawn in 3 stages and among capture year
Set 2	S_{sex}		Survival varied between male and female fawns
	S_{WAB}		Survival varied by estimated weight at birth (WAB)
	S_{CI}		Condition Index (CI) influenced survival

Table 2. A priori models used to determine variation in time dependence and the influence of individual covariates on survival of black-tailed deer fawns during the HLS interval (1 Dec-1 Mar) in the Hoko Game Management Unit, Washington, USA, during 2006-2009.

Model	Number of Parameters	Description
$S_{constant}$	1	Survival was constant over the time interval
S_{year}	3	Survival varied among the 3 capture years
S_{week}	13	Survival varied by week
$S_{week\ x\ year}$	39	Survival varied by year and week
$S_{nhls\ v\ hls}$	2	Survival varied by group
$S_{nhls\ v\ hls\ x\ year}$	6	Survival varied by group and year
$S_{nhls\ v\ hls\ x\ week}$	26	Survival varied by group and week
S_{hls}		Survival was influenced by the individual covariate HLS status

individual unmarked HLS fawns (identified by hair-loss pattern and location) and conducted observations, pairing them with known or marked NHLS fawns.

Observations were only conducted on animals standing (Mooring and Samuel 1999) for which activities were categorized as feeding, vigilant, grooming, running or other and quantified to the nearest second. Feeding included actively consuming food, either chewing or searching with head down and either standing in place or while walking. Vigilance was quantified as the amount of time an animal was alert and included looking up from a feeding bout with head raised to shoulders or above, with ears up and looking around, and included periods while chewing with head up. Grooming behaviors included oral self grooming, which was actively licking, biting or scraping areas behind the front shoulder with the mouth, and self scratching was actively scratching the head, neck or shoulders with the hind hoof (Mooring and Samuel 1999, Yamada and Urabe 2007). Mooring (1995) showed that allogrooming was important for the removal of ectoparasites on impala (*Aepyceros melampus*) and thus, I placed allogrooming behavior in the grooming category but only if it was reciprocal. If the focal animal was the only one grooming or receiving, those behaviors were placed in the "other" category. Running occurred if an animal was either startled or playing and was only recorded if the cause of running was not related to the observer. Surveys were discarded when the focal deer was affected by observer presence or ran out of sight prior to 10 min into the survey. All other activities were grouped into the "other" category. After 20 min, the location was recorded and microclimate and microhabitat variables were then collected.

Behavior Data Analysis

I dealt with small sample sizes by pairing NHLS and HLS individuals. Given the limitations of field conditions, some pairs were assigned after data were collected. This was achieved through physically matching deer post hoc, based on variables collected in the field including date, time of day, and weather. Pairing allowed me to make comparisons of NHLS and HLS deer while controlling for these variables. I tested for differences in foraging, scratching and vigilant behaviors among NHLS and HLS deer using paired t-tests. A Wilcoxon signed rank test was used for non-normal data determined by Shapiro-Wilk normality tests. I used repeated measures ANOVA in NCSS (Hintz 2007) to evaluate the change in behavior for marked NHLS and HLS deer that were observed multiple times over the course of the study. Proportions of time alert and feeding met assumptions of repeated measures ANOVA and did not require transformation. The proportion of time scratching violated the Box's M test for equality of between-group covariance for repeated measures analysis and was log transformed to fulfill this requirement.

Microhabitat and Microclimate

Following visual observations of fawns, I walked to the location and recorded temperature and wind velocity at 40 cm and at 150 cm above the ground using a handheld thermometer and anemometer (Kestrel 2500, Ambient Weather, Phoenix, AZ). The measurement at 40 cm represented conditions at the height of the fawn and 150 cm represented ambient temperature and wind velocity (Barrett 1981). The plot was located

where the animal was first observed. Since I was interested in microclimate and microhabitat, I selected random sites within the local habitat (Ratikainen et al. 2007) by assignment of a compass bearing and a distance between 100-150 m from the fawn location (Alldredge et al. 1991). To eliminate bias, I randomly selected the bearing and distance prior to conducting the survey using a random number generator in Microsoft Office Excel® 2003 (Microsoft Corporation, Redmond, Washington). I had an alternate direction selected, provided that the initial random location was placed in different habitat. For every fawn location, I recorded and measured the same climate and habitat variables for the random location used for paired comparisons (Mysterud and Ostbye 1995, Compton et al. 2002).

I was only able to conduct observations in clear-cut habitats, aged 0-9 years since harvest, which allowed me to control for habitat type (clear-cut). I recorded elevation, aspect, percent canopy cover, ground cover, and vertical structure of vegetation. I recorded the UTM location and elevation of each plot using a hand held GPS receiver (12XL, Garmin Ltd., Olathe, Kansas). I measured percent canopy cover from the center of the plot using a spherical densitometer (Lemmon 1956). Ground cover may have been important for protection from adverse weather as well as predators (Huegel et al. 1986, Bowyer et al. 1998), and vertical shrub density has been suggested to aid in thermoregulatory processes (Nudds 1977). I used a modified version of Nudds (1977) vertical density board to obtain a relative index of ground cover and vertical shrub density. The ground cover index was determined by measuring the distance at which the bottom 40 cm of the density board could no longer be seen due to obstruction from

surrounding vegetation within a 100 m radius. Vertical shrub density between the ground and 1.2 m above ground was estimated as the percent obstructed by vegetation within a 5 m radius. For both ground cover and shrub density the board was placed in the center of the plot and measurements were averaged from the four cardinal directions.

Microhabitat and Microclimate Data Analysis

Each fawn location was paired with a random location to determine if there were differences between the two sites based on microclimate and microhabitat variables. I used paired logistic regression (Compton et al. 2002, Keating and Cherry 2004) to determine which microhabitat and microclimate variables were used by fawns based on the strength of variable significance and model selection based on the Wald χ^2 probability. I used CLOGIT in program R to run the conditional logistic regression, which includes a strata category for analysis of paired data. I then compared models of NHLS fawns to those of HLS fawns for variables selected to determine if groups were using microhabitat variables differently.

Condition Assessment

Newborn Fawns

For fawns surviving beyond 1 December, serum constituents were determined for: insulin-like growth factor-1 (IGF1), total thyroxine (TT4), free thyroxine (FT4), total triiodothyronine (TT3), free triiodothyronine (FT3), urea nitrogen, glucose, alkaline phosphatase, creatinine, sodium (Na), potassium (K), Na/K Ratio, chloride, total CO2, calcium, phosphorus, magnesium, iron, total protein, globulin, total bilirubin (direct plus

indirect), aspartate aminotransferase, gamma glutamyl transferase, creatinine kinase and total cholesterol. Serum indices can be difficult to interpret due to differences in values related to capture stress, age and gender and should be used with caution when assessing condition (Anderson 1981, Watkins 1991, Cook 2002, Servello et al. 2005). IGF1, TT4, FT4, TT3, FT3, serum urea nitrogen and glucose were of particular interest based on their resistance to handling stress and their performance as nutrition indicators (Seal et al. 1978, Watkins et al. 1991, Brown et al. 1995, Cook 2002, Bishop et al. 2009). I used multiple analysis of variance (MANOVA) to determine differences in serum indices by age, gender, litter size, and year. Subsequent individual analysis of variance (ANOVA) was used to determine differences in specific serum values by sex and year between NHLS and HLS fawns. I used logistic regression analysis to identify variables possibly predisposing animals to louse infestation and subsequent hair loss as well as survival between 30 and 50 weeks of age.

Morphological measurements coupled with blood parameters provided an even better indication of nutritional condition of fawns at birth than serum indices alone. Robinette et al. (1973) showed that growth rate of fawns was relatively high during the first two weeks of age. For that reason, age of fawns was important in determining condition at birth since not all fawns were captured on the same day. I determined age of fawns and used growth rates (Brown 1961, Carstensen Powell and DelGiudice 2005) to back-calculate measurements of newborn fawns. Growth rates were estimated using linear regression equations. Age at capture and dates of birth were estimated, and then

means were compared for age and date of birth between male and female fawns among all capture years.

There have been some discrepancies between the equations developed to age fawns (Haskell et al. 2007) and none of them specifically used data from black-tailed deer. Therefore, I selected the methods first described by Haugen and Speake (1958) to measure new hoof growth of captured fawns and the equations developed by Robinette et al. (1973) to determine age of fawns. The Robinette et al. (1973) equations were produced from measurements of mule deer (*O. hemionus*) fawns, which are the same species as black-tailed deer (Wallmo 1981), compared to other age-estimating equations that were based on measurements of white-tailed deer (*O. virginianus*) fawns (Haugen and Speake 1958, Sams et al. 1996, Haskell et al. 2007).

I used MANOVA to determine the differences in morphological measurements based on age, gender, litter size and year. Subsequent individual ANOVA was used to determine differences in specific morphological measurements by year and sex. A condition index was estimated using ratios of girth and weight (CI = (intercept-weight) / chest girth, Martinez and Hewitt 1999), then incorporated into logistic regression equations to predict HLS infestation and survival.

Older Fawns

I estimated percent of body hairless and relative condition of fawns during observations from January through April (2008 and 2009). Percent of body hairless was estimated, for an index of HLS intensity, by visually dividing the fawn's body into

quadrants and determining the proportion of each section without hair. The method used to estimate relative condition of fawns was modified from Riney (1960). I assigned a condition score (poor=0, moderate=1, good=2) to each of five locations on the fawn's body by circling the letter corresponding to the condition observed for each individual (Figure 2). This provided me with a range of values used to index overall deer condition, where 0-2 was poor, 3-7 was moderate, and 8-10 was good. Mean condition values were compared between NHLS and HLS fawns using a two-tailed t-test. I used linear regression to test the correlation between proportion of body hairless and proportion of time spent scratching.

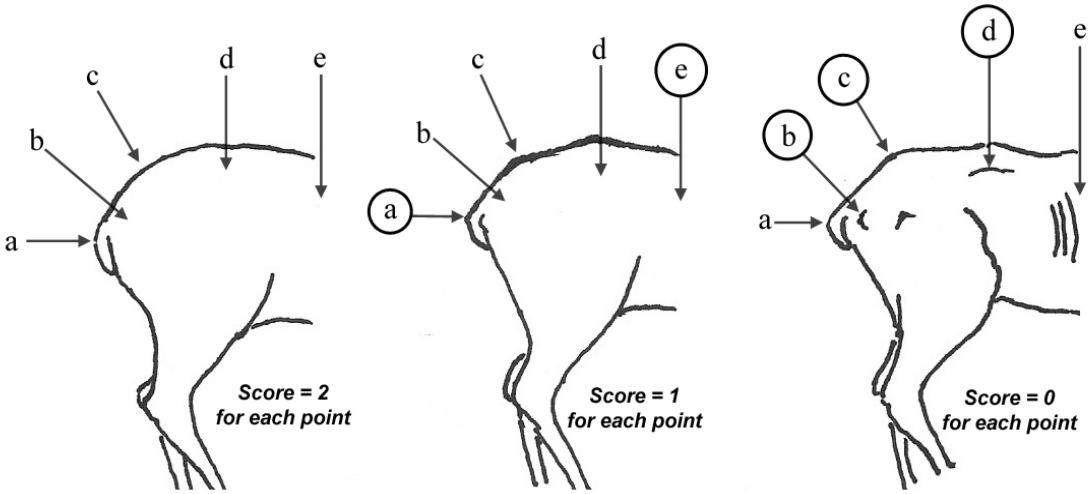


Figure 2. An example of how the diagram, modified from Riney (1960), was used to assign a condition index score to black-tailed deer with and without HLS in the Hoko Game Management Unit, Washington, USA, during winter 2008 and 2009. Deer condition is indicated by poor (far right), moderate (middle), and good (far left). A fawn with characteristics indicated by the circled letters would have a condition index score of two (a=1, b=0, c=0, d=0, e=1).

RESULTS

A total of 166 fawns were captured over 3 years, 50 in 2006, 50 in 2007 and 66 in 2008 (Appendix B-C). Four fawns were censored from all analyses due to mortality within 24 hours of capture. Lice were found on 23 fawns (14%) at capture. Of these, only six survived beyond 1 December. There were a total of 60 fawns included in the HLS analysis over the three years (21 in 2006-2007, 22 in 2007-2008, and 17 in 2008-2009) that were alive at the beginning of December. Overall prevalence of HLS was 43% (n=26) but was lower in 2008 (29%) compared to 2006 (48%) and 2007 (50%; χ^2_2 =10.4, *P*=0.005).

Survival

Forty fawns (24%) were censored from survival analysis over the study, nine (18%) in 2006, 10 (20%) in 2007 and 21 (32%) in 2008. Fawn survival from birth week to recruitment (50 weeks or 1 May) was 0.33 (95%CI=0.24-0.43) for 2006, 0.38 (95%CI=0.28-0.50) for 2007 and 0.40 (95%CI=0.30-0.50) for 2008 (Figure 3). Survival did not differ significantly between years (χ^2_2 =1.12 *P*=0.57) and average survival over all 3 years was 0.37 (95%CI= 0.27-0.48). The best model was explained by three intervals including early (first 9 weeks of life), HLS (1 Dec to 1 Mar), and all other weeks combined (10-29 and 43-50 weeks after the first fawn was born; Table 3).

Survival was not different among years for NHLS and HLS fawns (χ^2_2 =2.77, *P*=0.25), so all years (n=60) were pooled. Survival of NHLS fawns (0.79; 95%CI=0.62-90) was higher than survival of HLS fawns (0.57; 95%CI=0.38-0.73; *P*=0.058). Average

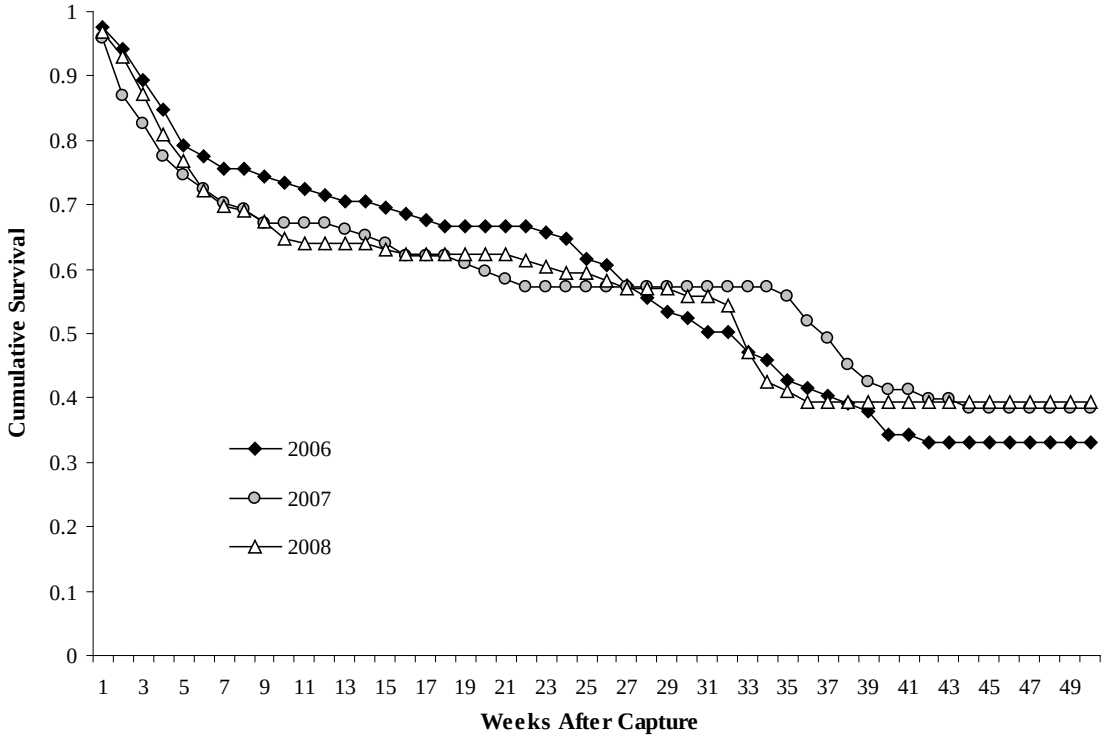


Figure 3. Cumulative survival curve showing overall black-tailed deer fawn survival over 50 weeks from birth week to recruitment (1 May) for 2006, 2007 and 2008 in the Hoko Game Management Unit, Washington, USA.

Table 3. Black-tailed deer survival model selection using program MARK (5.1, White 2008), showing AICc values, Delta AICc values, AICc weights, model likelihood, and number of parameters in each model for fawns in the Hoko Game Management Unit, Washington, USA.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	Parameters
$S_{age\text{-}3intervals}$	1603.63	0	0.954	1	4
$S_{age\text{-}3intervals \times year}$	1609.71	6.08	0.046	0.048	10
$S_{age\text{-}2intervals}$	1628.25	24.62	0	0	3
$S_{age\text{-}2intervals \times year}$	1630.39	26.76	0	0	7
S_{age}	1636.37	32.74	0	0	51
$S_{constant}$	1667.83	64.20	0	0	2
S_{year}	1671.46	67.83	0	0	4
$S_{age \times year}$	1748.33	144.70	0	0	150

survival of fawns from 1 December to 1 March, was 0.64 (95%CI=0.37-0.84). The best model explained that survival from December to March was influenced by week and incidence of HLS (Table 4). The interval characterized by HLS (1 Dec-1 Mar) showed the lowest rates of survival over the entire year, even compared to the first nine weeks. The average survival through the first 9 weeks of life was similar among years at 0.71 (95%CI=0.57-0.82).

Predation was the leading cause of mortality throughout the study, where cougars were the greatest source of predation, resulting in 40% of all mortalities, followed by bobcats, bears and coyotes (Table 5). The high percentage of unidentified predation events in year 3 occurred primarily in December, due to a major winter storm that prevented access to the study area for two weeks, and very early mortalities of fawns that were either completely consumed or unrecovered and predator identification could not be determined. Non-predation natural events included abandonment, poor nutritional condition and developmental problems. The human-related mortalities included one capture related and two illegally harvested. The capture related mortality occurred following the recapture of a radio-collared fawn, seven months old that died less than 24 hours later. The two illegally harvested fawns were siblings found shot during a non-hunting season. Twenty of the 60 fawns at risk beyond 1 December died, 17 from predation, one from natural causes, and two unknown. Condition assessment of fawns based on examination of bone marrow indicated severely to moderately poor nutritional condition in 16 of 18 fawns (89%); only one of those was not predator related. Six of eight (75%) NHLS fawns and nine of nine (100%) predated HLS fawns showed signs of

Table 4. Black-tailed deer fawn survival model selection for the hair loss syndrome (HLS) time interval (1 Dec-1 Mar) using program MARK (5.1; White 2008), showing AICc values, Delta AICc values, AICc weights, model likelihood, and number of parameters in each model for fawns in the Hoko Game Management Unit, Washington, USA.

Model	AICc	Δ AICc	AICc Weight	Model Likelihood	Parameters
$S_{week\ x\ hls}$	270.50	0	0.652	1	14
S_{week}	272.38	1.89	0.254	0.389	13
$S_{constant}$	275.97	5.47	0.042	0.065	1
$S_{nhls\ v\ hls}$	277.01	6.52	0.025	0.038	2
S_{year}	278.16	7.67	0.014	0.022	3
$S_{week\ x\ year}$	278.59	8.09	0.011	0.018	39
$S_{nhls\ v\ hls\ x\ year}$	283.06	12.57	0.001	0.002	6
$S_{nhls\ v\ hls\ x\ week}$	291.27	20.77	0	0	26

Table 5. Cause-specific sources of mortality for black-tailed deer fawns during 2006-2009 in the Hoko Game Management Unit, Washington, USA.

Source	2006-2007		2007-2008		2008-2009		Total	
	n	Percent	n	Percent	n	Percent	n	Percent
Predation	25	83.3	20	76.9	26	81.3	71	80.7
Cougar	12	40.0	13	50.0	11	34.4	36	40.9
Bobcat	7	23.3	2	7.7	1	3.1	10	11.4
Bear	2	6.7	1	3.8	0	0	3	3.4
Coyote	1	3.3	0	0	0	0	1	1.1
Unknown predation	3	10.0	4	15.4	14	43.8	21	23.9
Non-predation Natural	2	6.7	5	19.2	4	12.5	11	12.5
Unknown	0	0	1	3.8	2	6.3	3	3.4
Human	3	10.0	0	0	0	0	3	3.4
TOTAL[a]	30	60.0	26	52.0	32	48.5	88	53.0

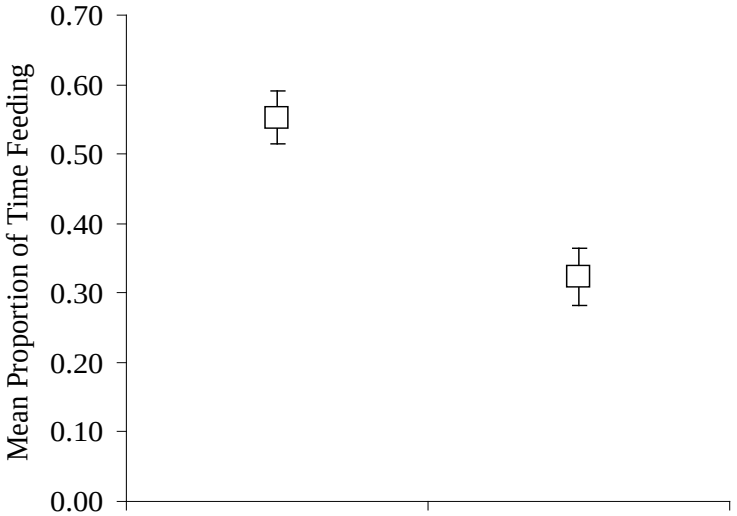
poor condition. Two NHLS fawns that died from predation had bone marrow indicative of relatively good condition at time of death. The condition of two HLS fawns was unknown due to a lack of evidence at the mortality site. Predation rates among HLS fawns (35%) were not significantly different than those of NHLS fawns (24%; P=0.19).

Behavior

I recorded 53 hours from 168 independent observations of fawns in 2007 and 2008, and ultimately obtained 20 unique pairs of HLS and NHLS fawns for analysis. The proportion of time spent feeding was higher among NHLS compared to HLS deer (Wilcoxon signed rank test, n=20, P=0.0005, Figure 4), and the proportion of time spent scratching was lower among NHLS compared to HLS deer (Wilcoxon signed rank test, n=20, P=0.0001, Figure 4). The proportion of time alert was not different between NHLS (0.35 ± 0.033; $\bar{x}$ ± SE) and HLS (0.41 ± 0.044) deer (Wilcoxon signed rank test, n=20, P=0.3).

Repeated measures ANOVA tests indicated a difference between NHLS and HLS deer for time spent feeding ($F_{1,49}$=7.24, P=0.013) and scratching ($F_{1,45}$=20.58, P=0.0001), as well as an increase in scratching behavior among individuals over time ($F_{1,45}$=4.77, P=0.04), for both NHLS and HLS fawns from January to March (Figure 5). There were no significant interactions between NHLS and HLS fawns for any behavior over time (P>0.38). The percent of hair loss was not related to the proportion of time spent scratching by HLS fawns (R^2=-0.045, $F_{1, 22}$=0.013, P=0.9).

Feeding



Scratching

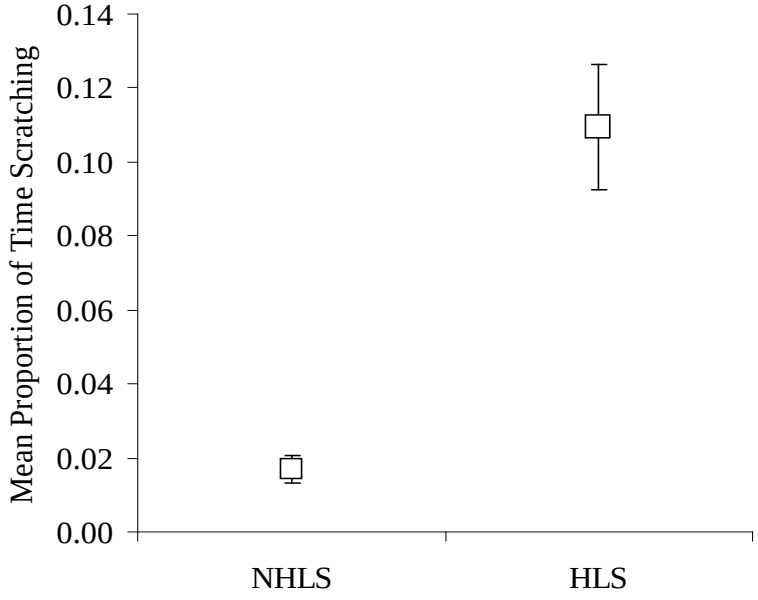
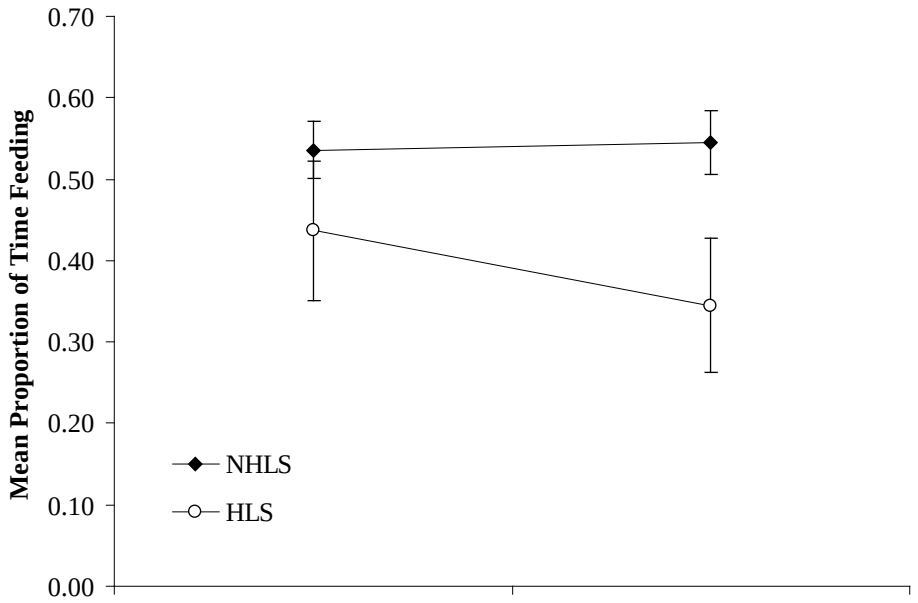


Figure 4. The mean proportion of time spent feeding and scratching among all pairs (n=20) of non-hair loss syndrome (NHLS) and hair loss syndrome (HLS) fawns in the Hoko Game Management Unit, Washington, USA; bars represent ±1 SE.

Feeding



Scratching

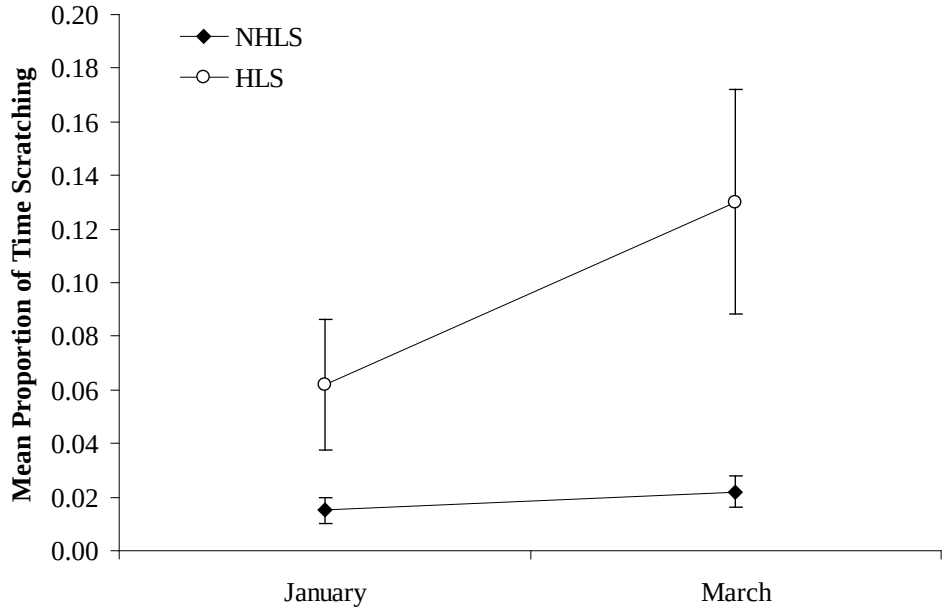


Figure 5. The mean proportions of time spent feeding and scratching showing trends of individuals over time, from January to March 2008 and 2009, for non-hair loss syndrome (NHLS, n=18) and hair loss syndrome (HLS, n=7) fawns in the Hoko Game Management Unit, Washington, USA. Bars represent ± 1 SE.

Habitat

I measured microhabitat and microclimate variables for a total of 70 paired observations of fawn locations and random locations (45 NHLS and 25 HLS) in 2008 and 2009. The NHLS deer locations were represented by 24 unique individuals with all but three fawns being sampled twice. The HLS deer locations were represented by 17 unique individuals with eight fawns being sampled twice in 2008. The sample size distribution was not completely even but samples were representative of the population. All fawns were found in locations with greater canopy cover (6.1±1.6 v. 3.0±0.6, $P<0.03$) and mean ground cover (25.6±1.4 v. 22.7±1.2, $P<0.06$) but with less mean shrub density (19.8±1.7 v. 23.3±2.0, $P<0.06$) and lower elevation (169±8.8 v. 175.1±8.8, $P<0.03$; Table 6). Fawns were also located in areas with higher temperatures (40 cm: 7.0±0.3 v. 6.7±0.3, $P<0.02$; 150 cm: 6.5±0.3 v. 6.3±0.03, $P<0.01$) and lower wind speeds (40 cm: 0.36±0.03 v. 0.045±0.05, $P<0.05$; 150 cm: 0.75±0.06 v. 0.95±0.09, $P<0.01$) relative to random locations (Table 6).

Canopy cover, mean shrub density, and temperature at 40 cm off the ground were the best predictors of fawn locations (Table 7). NHLS fawns also selected locations lower in elevation than random sites ($\chi^2_1=6.56$, $P=0.01$); and elevation was the only variable among microhabitat and microclimate that was selected differently between NHLS and HLS fawns (AIC: 91.2, ΔAIC=6.3), where HLS fawns were found at lower elevations compared to NHLS fawns ($Z=-1.94$, $P=0.05$; Table 6).

Table 6. Mean and standard errors (SE) for microhabitat variables, percent canopy cover, mean ground cover index, mean shrub density, elevation and microclimate variables, temperature at 40 cm off ground, temperature at 150 cm off ground, wind speed at 40 cm off ground, wind speed at 150 cm off ground, tested between fawn locations and random sites for non-hair loss syndrome (NHLS) and hair loss syndrome (HLS) deer in the Hoko Game Management Unit, Washington, USA.

	NHLS				HLS			
	Fawn Location		Random		Fawn Location		Random	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Canopy Cover (percent)	6	2	3	1	7	2	3	1
Mean Ground Cover Index (percent)	25	2	23	2	26	2	22	2
Mean Shrub Density (percent)	19	2	21	2	22	3	28	3
Elevation (m)	193	11	203	11	127	9	126	9
Temperature at 40 cm above ground (^{o}C)	6.88	0.32	6.62	0.33	7.10	0.55	6.86	0.58
Temperature at 150 cm above ground (^{o}C)	6.44	0.30	6.15	0.31	6.65	0.55	6.47	0.53
Wind Speed at 40 cm above ground (m/sec)	0.35	0.05	0.46	0.07	0.40	0.05	0.43	0.09
Wind Speed at 150 cm above ground (m/sec)	0.74	0.08	0.93	0.10	0.78	0.09	1.00	0.17

Table 7. Coefficients, standard error (SE), Z-value and p-value for significant terms in the paired logistic regression model describing selected variables for deer fawn locations versus random sites in the Hoko Game Management Unit, Washington; the model Location ~ canopy cover + mean shrub density + temperature at 40 cm above ground + Strata (Pair_ID) was selected, χ^2_3 =12.4, *P*=0.006.

	Coefficient	SE	*Z*	*P*
Canopy Cover	0.1136	0.0545	2.08	0.037
Mean Shrub Density	-0.0593	0.0226	-2.63	0.009
Temperature at 40 cm above ground	0.9212	0.3292	2.80	0.005

Condition

Slope of regression equations (Table 8, Figure 6) were used as growth rates, to estimate morphological measurements of fawns at birth. The condition index (CI) used for all fawns was CI = (23.47 – weight (kg))/girth (cm).

All morphological measurements at capture and estimates of measurements at birth were summarized showing mean values among male and female fawns for all years (Appendix D). Femur measurements were not analyzed due to high variability between years and among individuals taking measurements. Girth ($F_{1,159}$=20.7, P<0.0001), girth at birth ($F_{1,156}$=30.7, P<0.0001), condition index ($F_{1,159}$=11.3, P=0.001) and condition index at birth ($F_{1,159}$=23.2, P<0.0004) differed by year. There were no differences based on litter size, and there were no interaction effects between sex, year and litter size, on remaining morphological measurements or estimated at-birth measurements (P>0.10). Mean weights of fawns at capture were not significantly different between male and female fawns ($F_{1,156}$=3.05, P=0.083) or between years ($F_{1,156}$=1.51, P=0.22). However, estimated mean weight of fawns at birth was significantly different between male and female fawns ($F_{1,156}$=5.71, P=0.018), with males on average heavier than females, and between years ($F_{1,156}$=6.49, P=0.012), with 2006 having the heaviest weights and 2008 the lightest.

Neither morphology nor condition indices were good predictors of overall survival (P>0.26) or development of HLS (P>0.11). All mean values of morphology and condition were similar between NHLS and HLS individuals (Appendix E).

Table 8. Regression equations of the relationship between age and morphological measurements of black-tailed deer fawns at capture, where slope was used as the growth rate to back calculate morphological measurements for an estimate of at birth values for all years (2006-2008) within the Hoko Game Management Unit, Washington, USA.

Equation	R^2	*F*	*Df*	*P*
Weight = 2.935 + 0.29*Age	0.53	130.6	112	<<0.001
Hind Foot = 23.34 + 0.37*Age	0.30	48.98	112	<<0.001
Length = 57.17 + 0.95*Age	0.23	35.34	112	<<0.001
Girth = 31.43 + 0.54*Age	0.21	30.93	112	<<0.001

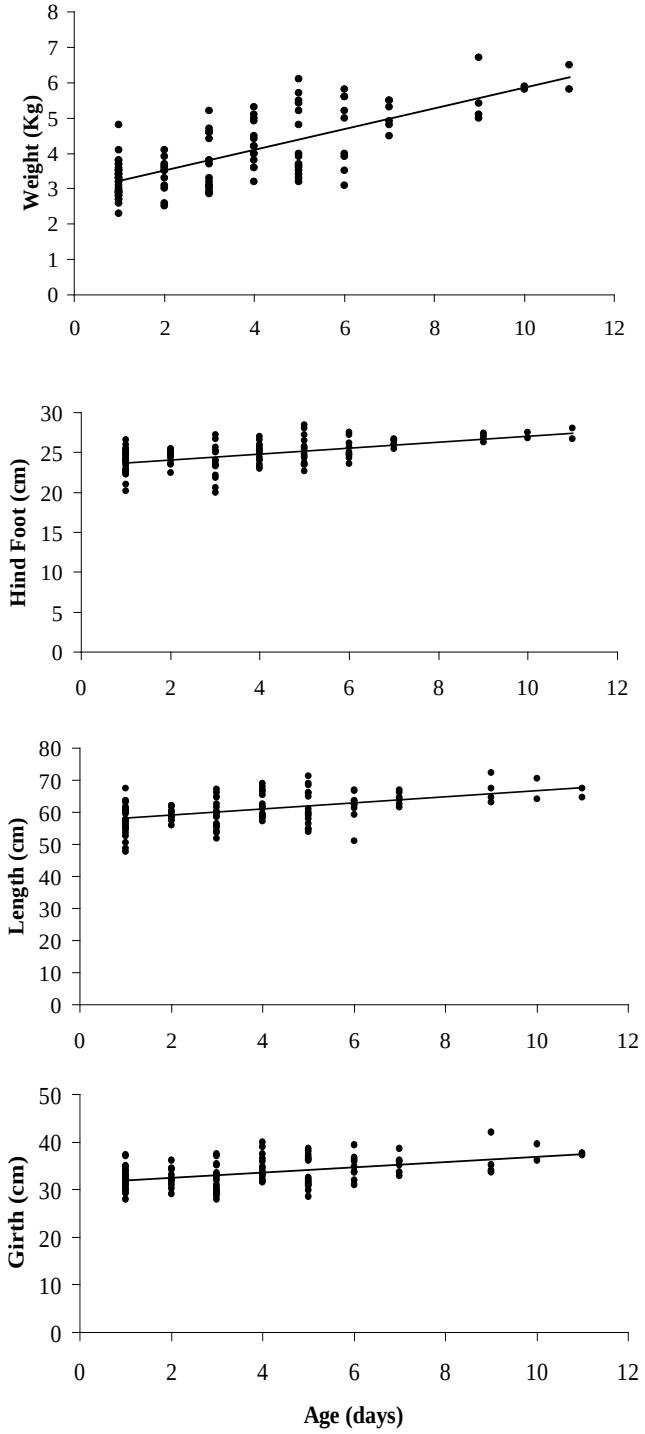


Figure 6. Graphs showing the relationship between weight, hind foot, length and girth measurements to age in days at capture, the slope of the regression equations were used as growth rates to back calculate measurements of fawns at birth from 2006-2008 in the Hoko Game Management Unit, Washington, USA.

A total of 44 serum samples were submitted for analysis. Means between NHLS and HLS deer were different for glucose, phosphorus and magnesium, which were all higher among NHLS than HLS fawns (Table 9). There were no differences in serum concentration values based on age, gender, or litter size nor were there any interaction effects on serum concentration values. However, serum concentration values for TT3, magnesium, sorbitol dehydrogenase, sodium, chloride, aspartate aminotransferase, and CO2 were higher and FT3 was lower for the 2008 fawn cohort compared to the 2007 cohort (Appendix F).

The only serum value that was correlated to HLS in fawns among those selected for analysis, was glucose concentration (Z=-2.359, P=0.018). Glucose showed a weak relationship to weight at capture, with heavier fawns having higher levels of glucose (R^2=0.2, F_{44}=10.79, P=0.002) than lighter fawns. Serum concentration values of fawns at capture were not good predictors of survival for fawns from December to May (P>0.15).

Mean percent of hair loss for HLS fawns (n=26) was 27% (±5%) and ranged from 0-75% from late December through April. Mean body condition scores were higher among NHLS (5.9 ± 0.25) fawns than HLS (3.4 ± 0.35) fawns (t_{30}=5.59, P<0.0004). There was a negative relationship between percent hair loss and body condition index score (R^2=0.71, $F_{1,24}$=61.75, P<0.0004; Figure 7).

Table 9. Means and standard errors (SE) of serum glucose, phosphorus and magnesium concentrations of black-tailed deer fawns at capture that survived to December, which were significantly higher among non-hair loss syndrome (NHLS) fawns compared to fawns with hair loss syndrome (HLS) in the Hoko Game Management Unit, Washington USA. Wilcoxon signed rank tests (p-value) used for non-normal data and t-tests (t-statistic and p-value) used for normally distributed data.

	NHLS		HLS		Statistics
	Mean	SE	Mean	SE	
Glucose (mg/dL)	158.07	8.36	122.38	6.54	Wilcoxon P=0.002
Phosphorus (mg/dL)	10.52	0.27	9.36	0.34	t_{33}=2.59, P=0.014
Magnesium (mg/dL)	2.49	0.07	2.26	0.07	t_{38}=2.25, P=0.030

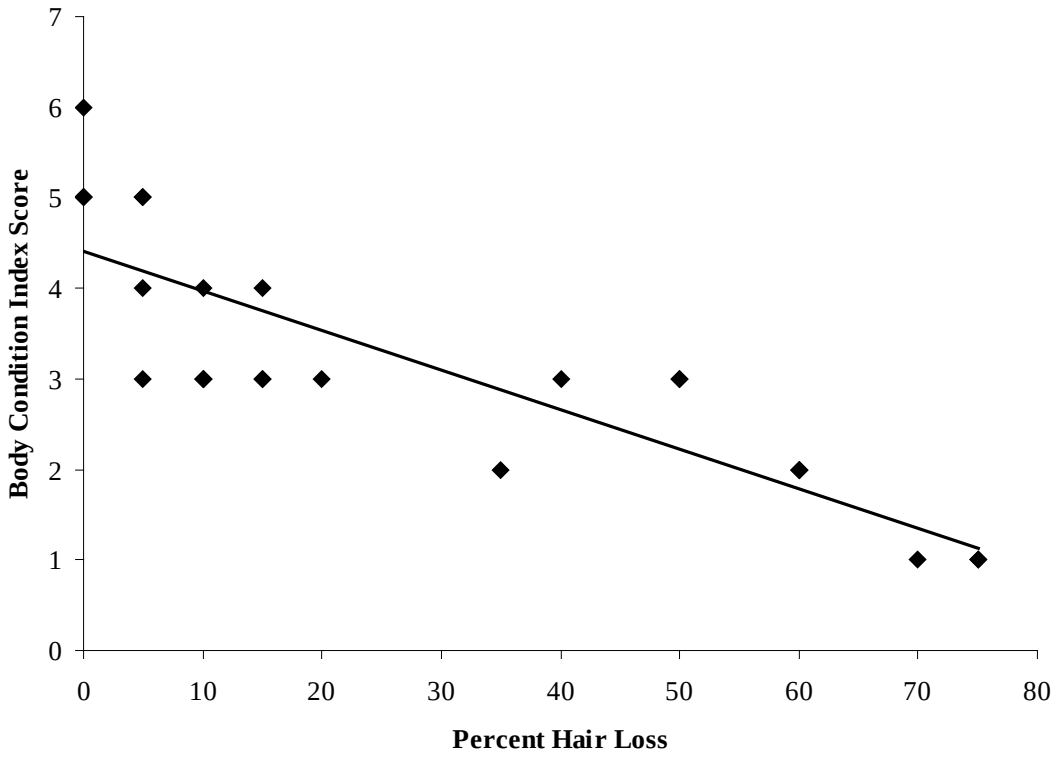


Figure 7. Relationship between percent hair loss and over-winter body condition index score of hair loss syndrome (HLS) deer (n=26) during 2007-2008 and 2008-2009 winter survey periods in the Hoko Game Management Unit, Washington, USA.

DISCUSSION

Hair loss syndrome influenced behavior of fawns and had an indirect effect on survival. Feeding behavior was significantly reduced and scratching behavior was significantly greater for HLS fawns, and was related to lower body condition compared to NHLS fawns. Predation was the greatest proximate source of mortality, given that 89% of fawns that died from predation were also moderately to severely nutritionally stressed, based on bone marrow examination. Marrow fat is the last fat deposit to be fully mobilized before starvation and can be a good indicator of poor condition at time of death (Riney 1955, Takatsuki 2001, Murray et al. 2006). When malnutrition and parasitism co-exist, effects of immunosuppression and host energy depletion interact such that host condition and survival are further compromised (Murray et al. 2006). Although survival of NHLS fawns was only marginally statistically greater than HLS fawns, hair loss syndrome is probably biologically significant, and possibly an additive source of mortality. Poor condition coupled with the effects of HLS influenced recruitment rates due to low over winter survival of fawns. This was supported by survival rates between December and March, which were the lowest rates seen over the entire biological year, in all years of the study. Further support was provided by Year 3, having the highest survival rate of all years and the lowest prevalence rates of HLS, yet challenging winter conditions and the longest lasting snowfall of all three years.

Survival

Fawn mortality is typically highest during the first 60 days of life (Steigers and Flinders 1980, Temple 1982, Hamlin 1984, Hatter 1988, Mackie et al. 1998, Whitaker and Lindzey 1999, Vreeland 2002, Rohm et al. 2007). Survival of deer can be limited by many factors, where fawns are particularly susceptible to early mortality through predation (Whittaker and Lindzey 1999; Vreeland et al. 2004; Rohm et al. 2007), poor nutritional condition (Lomas and Bender 2007), adverse weather conditions (Gilbert and Raedeke 2004), disease (Carroll and Brown 1977) or a combination of these. Similarly, fawn mortality in the Hoko GMU was high throughout the first 9 weeks of life, but it was even higher during the December to March time frame, resulting in an even greater impact to overall fawn survival and recruitment than early mortality alone.

Fawns are especially vulnerable to over winter mortality due to accelerated depletion of limited fat reserves and muscle catabolism (Parker et al. 1999; Taillon et al. 2006). Snow accumulations increase energetic costs and cause an increase in nutritional stress on young deer that require resources to support both growth and maintenance (Parker et al. 1999, Farmer et al. 2006). Six fawns died during a severe winter storm in 2008-2009 where 60-90 cm of snow covered the study area for two weeks. At least two were fawns with HLS and two were unable to be classified due to carcass decomposition and hide deterioration. Significant increases in energetic costs were associated with temperatures falling below thermo-neutral limits of Sitka black-tailed deer (*O. h. sitkensis*), snow accumulations over 24 cm, and high amounts of rainfall in coastal coniferous forests of southeast Alaska, (Parker et al. 1999). Environmental factors, such

as those listed above, were likely underestimated during this study and coupled with the loss of hair among HLS fawns probably contributed to greater susceptibility to mortality. Parker et al. (1999) found that intake of digestible energy was the primary limiting factor during the winter rather than direct energy expenditure, further compromising fawns with HLS due to reductions in time spent feeding.

Small sample sizes throughout the years may have affected our ability to detect more extreme differences in survival among HLS and NHLS fawns. Beginning in December, there were 17-22 fawns at risk each year. A prevalence rate of 43% meant that only 6-11 HLS fawns and 9-12 NHLS fawns were available for analysis per sample year. Even with small sample sizes, evidence showed that mortality rate of HLS fawns was twice as high as NHLS fawns (0.43 vs. 0.21) and HLS fawns had a much lower condition index (3.4 vs. 5.9) than NHLS fawns.

Behavior

HLS fawns spent a significantly greater proportion of time scratching and a significantly lower proportion of time feeding than NHLS fawns. These results support my hypothesis that HLS influences fawn behavior and were similar to results from Robison (2007) and as suggested by Bildfell et al. (2004) and Foreyt et al. (2004). Interestingly, the proportion of time alert was not different between NHLS and HLS fawns, and was even slightly higher among HLS fawns. This did not support my prediction that increased time scratching would result in reduced time spent vigilant, thereby increasing probability of predation. Alternatively, HLS deer may have

compensated for a perceived risk of predation by increasing their vigilant behavior (Mooring et al. 2004b), resulting in further decreases in foraging rates (Ratikainen et al. 2007).

It has been documented that vigilance is different for individuals based on group size and the number of individuals being vigilant. I did not measure group size while performing observations to determine vigilant behaviors in a group dynamic. However, during my observations, groups typically ranged from 2-4 deer for both NHLS and HLS fawns. Mooring et al. (2004b) found that individual rates of vigilance in impala increased in groups of less than five animals, and may explain the lack of difference in vigilant behavior between NHLS and HLS fawns.

Proportion of time spent scratching increased over time (from early January to late March) among individuals. This increase occurred for both NHLS and HLS deer, likely resulting from scratching behaviors consistent with losing the winter coat in early spring. Robison (2007) saw hair loss symptoms into early summer, but I observed fawns recovering from HLS symptoms by the end of April. Two fawns recaptured in late April or early May had been identified as having >75% hair loss but, in areas where guard hairs had been broken off, a healthy summer coat had begun to grow.

The range of hair loss among fawns was 0-75% and was not related to the amount of time spent scratching. The percent of hair loss could have been related to the time frame in which deer developed the disease. Fawns that began scratching in December would have had a greater proportion of body hairless compared to fawns that began scratching in February. Initial clinical signs of HLS were observed as early as December

and as late as March. Why fawns began to show clinical signs at different times of the year or why there was a delay in onset of lice infestation in some fawns was unknown. Of the fawns that ultimately showed clinical signs of HLS (n=26) only two (7.7%) had lice at time of capture, indicating that development of HLS was independent of lice infestation at that time.

Habitat

Microhabitat and microclimate use by deer indicated a trade-off between forage quality and quantity, hiding cover from predators, and a need for increased thermal cover in the winter. Open habitats typically contain higher biomass of quality forage than more dense herbaceous sites (Massé and Côté 2009). Risk of predation plays a role in decisions made at the microhabitat level (Huegel et al. 1986, Barrett 1981, Whittaker and Lindzey 1999), resulting in differences in use of vertical cover of vegetation (Nudds 1977). In my study, fawns were selecting microhabitats and microclimates based on weather and thermal cover requirements (Mysterud and Ostbye 1995, Ratikainen et al. 2007), where trade-offs were made between good forage, hiding cover and microclimate, similar to results found by Bowyer et al. (1998). Deer were found in local sites with greater canopy cover and temperature at the height of the fawn, and with lower mean shrub density than random sites. The mean shrub density characterized the vertical profile of vegetation within a 5 m radius of the plot center, and indicated a more open vertical structure, likely providing greater forage biomass (although this was not measured in my study). Even though ground cover wasn't statistically significant, slightly higher values at locations relative to random sites indicated that chosen sites

consisted of some hiding cover at the height of the fawn within a 100 m radius, while also allowing for a less obstructed view to monitor surroundings. Temperatures at the height of the fawn were higher at locations than random sites, indicating that fawns were selecting sites with better thermal properties during the winter. The lack of different microhabitat and microclimate variables selected between NHLS and HLS fawns, and the lack of significantly higher predation rates of HLS fawns suggests that deer were already maximizing forage and thermal cover, while sacrificing some risk of predation.

Elevation was different between fawn location and random sites for NHLS deer, but not for HLS deer. NHLS fawns were using lower elevations compared to random sites relative to wind and temperature variations. In addition, NHLS fawns were found at higher elevations on average compared to HLS fawns. Since I did not measure available habitat, I could not predict whether HLS fawns were selecting lower elevations relative to NHLS fawns. Even though mean differences were only 70 m in elevation, it could support the theory that HLS is more abundant among fawns at lower elevations, which has been previously suggested (Bender and Hall 2004, Bildfell et al. 2004). Alternatively, use of lower elevations by HLS fawns could simply be coincidental, but further research with greater elevation gradients is necessary to make this conclusion.

Condition

Based on morphological measurements, condition of fawns at birth or at capture were not related to the overall survival of fawns or to the development of HLS later in life. The condition index did not indicate differences between fawns that died compared

to those that lived, or fawns that developed HLS and those that did not. Given the survival rate of our fawns, and the high variability in fawn measurements, it was not surprising that there were no differences detected.

Serum values at capture were not important predictors of fawn survival from December through March, although only a relatively small sample (n=44) of serum values were analyzed from fawns surviving to December, among 2007 and 2008 cohorts. Some mean serum values were significantly lower among HLS fawns including serum concentrations of glucose, magnesium, and phosphorus. Glucose is the primary source of energy, where low serum levels indicate inadequate energy consumption. Handling stress that causes excitement may also increase glucose levels (Russell & Roussel 2007). However, handling time was very minimal and most fawns did not show physical signs of excitement during processing. Even though glucose values were lower among HLS fawns, they still fell within reference intervals of published values for black-tailed deer (Anderson 1981), elk (Cook 2002) and cows (Kahn 2008). Serum glucose concentration has been shown to vary significantly based on weight of elk calves (Cook 2002), and similar results were true for weights of our fawns. There was a correlation between higher levels of serum glucose concentration and larger fawns in our study, but the relationship was weak, only accounting for 20 percent of the variation.

Magnesium is a critical nutrient for ruminants, functions at three levels (enzymatic, ribosomal and whole cell), and is extremely important for many metabolic processes (Fontenot et al. 1989). Both NHLS and HLS serum concentrations were above the severe deficiency threshold (<1.0 mg/dL) at 2.26 and 2.48 mg/dL, respectively.

These values are also within reference intervals published for mule deer (Anderson 1981) and cows (Kahn 2008).

Phosphorus values for both NHLS and HLS fawns were higher than reference intervals for both elk calves (Cook 2002) and cows (Kahn 2008), but were within reference intervals published for mule deer (Anderson 1981). Hyperphoshpatemia is likely a result of dehydration (Russell & Roussel 2007) and may have simply been related to the timeframe in which fawns had last nursed.

It may be coincidental that glucose, magnesium and phosphorus were higher among NHLS fawns or the differences we saw may have been due to differences in sample sizes between the two groups, simply leading to higher variation. Serum analysis should be included for all fawns in the future, to examine at-capture blood parameters and their influence on early survival.

Measurements and blood analyses were performed on fawns at capture and do not represent the condition of fawns at the onset of winter. There was minimal evidence to suggest that NHLS fawns were in significantly better health than HLS fawns, especially given that we did not recapture fawns prior to 1 December. Visual condition indices of fawns throughout the winter did however indicate that HLS fawns were in much poorer condition than NHLS fawns, similar to results of Bildfell et al. (2004) and Foreyt et al. (2004). This was supported in three ways: 1) mean condition index was significantly higher for NHLS fawns than HLS fawns, 2) there was a negative relationship between body condition score and the percent of hair loss experienced by HLS fawns, and 3) in spite of low sample size, data from a concurrent study showed that weight of NHLS

fawns was greater than weight of HLS fawns recaptured in April (S. Murphie and R. McCoy, unpublished data). The condition of HLS fawns was limited by factors leading up to and during the winter rather than those at birth. Such factors may have included condition or nutritional deficiencies of the doe during lactation or the ability of the fawn to obtain adequate immune defenses (Sams et al. 1996), poor nutritional quality of summer or autumn forages (Cook et al. 1996, Farmer et al. 2006), or amount and extent of contact with animals infected with exotic lice. Fawns were evidently exposed to lice at a very young age, since 14% of fawns had lice on them at the time of capture. Lice at capture did not appear to influence the development of HLS but sample sizes were very low due to the high number of early mortalities. Alternatively, some of the condition assessments of fawns may have been confounded by the condition of the doe during gestation, especially with twins (Parker et al. 1999), leading to reduced fitness of fawns at birth (Robinette et al. 1973, Thorne et al. 1976, Mueller and Sadleir 1980).

Measurements, morphology based condition indices and blood analyses were taken from fawns at the time of capture. There would be value in having the same information for fawns at the beginning of December, and again in April, to identify conditional constraints and parasite loads at the beginning of the most critical time period; and to evaluate possible recovery at the end of this time period.

MANAGEMENT IMPLICATIONS

Assessing the direct influence of HLS on fawn survival was hindered by the high rate of predation observed in this study and the resulting small sample of fawns available for analysis. It was unknown if HLS alone would result in death. It is likely that some mortality would occur, based on condition data of HLS fawns from this and other studies (Bildfell et al. 2004, Foreyt et al. 2004, Robison 2007), but the extent is unknown. My results provide preliminary evidence that poor condition, exacerbated by behavior and energy consequences of HLS, may be influencing recruitment rates due to low over-winter survival of fawns. To date, a treatment for HLS among free-ranging deer has not been developed; thus, addressing low recruitment may be limited to improving range conditions, reducing harvest, or reducing predation.

The poor nutritional quality of winter forage in coastal forests leads to potential limitations among deer to maintain body condition throughout the winter (Parker et al. 1999). Forage quality throughout summer and autumn was also important for growth and over-winter survival of young deer (Farmer et al. 2006) and elk (*Cervus elaphus*) calves (Cook et al. 1996). Forage quality and quantity limitations may have prevented HLS fawns from performing better. Forage data, based on elk research within the Hoko GMU (Hutchins 2006, Boyd 2009) indicated adequate conditions throughout the area. However, deer are distributed differently from elk and are limited to forage and habitat conditions within smaller home ranges that may be influenced more by timber harvest levels and stand age composition (Farmer et al. 2006). Deer have been shown to select

shrub communities in logged forests less than 10 years old (Yeo and Peek 1992). Limitations to deer within our study area may depend on stand age composition within their home ranges. Habitat manipulations, supplemental feeding and forage enhancements have been used to overcome range limitations, but their use has largely been targeted toward elk (Weckerly 2005, Long et al. 2008) and white-tailed deer in the east (Brown and Cooper 2006). These types of treatments may improve range conditions providing benefits to deer populations (Bishop et al. 2009b) but remain controversial and may only provide short-term benefits. Further, many areas of research are conducted on private timberlands and habitat manipulation may not be an option.

Similar research should be conducted in other areas of western Washington to determine the role that predators play in survival of black-tailed deer fawns, especially in areas affected by HLS. Where possible, all factors responsible for limiting populations should be evaluated and addressed. Locally, the deer population is limited by recruitment and managers should take appropriate actions to maximize fawn productivity and survival. In areas where populations are below management objectives, managers should consider reducing doe harvest to maintain productivity levels. Doe harvest should be eliminated in areas exhibiting high rates of decline to maximize productivity. If predation is determined to be the primary limiting factor, and reductions or elimination of doe harvest have limited effects, short-term predator control may be the only way to restore healthy prey populations at risk (Ernest et al. 2002).

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Appendix A. Mortality site characteristics of four primary predators of black-tailed deer fawns including cougar (*Puma concolor*), bobcat (*Lynx rufus*), black bear (*Ursus americanus*) and coyote (*Canis latrans*) occurring within the Hoko Game Management Unit, Washington, USA.

Cougar

- Punctures in head or neck or in rostrum and associated with a crushed skull.
- Punctures approximately 0.4-0.6 cm in diameter and 3.8-5.7 cm apart.
- Carcass mostly to completely cached using surrounding vegetation or ground litter or snow when present.
- Carcass entered through the abdomen with internal organs consumed first.
- Young fawns frequently completely consumed with exception of tail and hooves.
- Older fawns partially to completely consumed with the exception of tail, hooves, hide, stomach, rumen, intestines, and sometimes head and long leg bones; femurs usually eaten.
- Scat and tracks typically within 15 m of kill site, occasionally latrine sites were found consisting of remains and collar urinated on.
- Tracks of adults were generally 7.6-8.9 cm long by 8.9-9.5 cm wide for the front, and 7.6 cm long by 8.6 cm wide for the hind foot.
- Most cougar mortality sites were in cover, with vegetation matted down and a relatively organized nature to carcass and pile of remains. Sometimes, if fawn was completely consumed, cougars did not bother covering remains.
- Depending on the amount of time between kill and recovery, typically young fawns (< 3 mo of age) were consumed within 12-18 hrs, whereas older fawns (6-10 mo of age) were consumed within 24-48 hrs.

Bobcat

- Punctures, bruising, and/or scratches in head or neck and other parts of body.
- Punctures approximately 0.1-0.3 cm in diameter and 2-2.5 cm apart.
- Carcass partially to mostly cached using surrounding vegetation, ground litter or over-hanging vegetation, or snow when present, usually not covered as well as cougar kills and cover was concentrated on areas that had been exposed.
- Carcass entered at hind quarters or shoulder/neck, but occasionally entered through abdomen, especially on young fawns.
- Primarily consumes meat, especially on older fawns, but will consume liver and heart, especially on young fawns. Also, remains have an organized nature similar to that of cougars but will leave whole legs and hide; sometimes breaks femurs to eat marrow.
- Occasionally, bobcats will chew nose and ears, similar to coyote behavior.
- Tracks typically found within 5-10 m of kill site and characterized by 4.8 cm long by 4.4 cm wide for the front, with similar measurements for the hind foot.

- Most mortality sites were in cover, but trails and areas of matted down vegetation not as obvious as those at cougar sites.
- Typically young fawns (<3 mo) were consumed within 16-48 hrs, whereas older fawns (6-10 mo) were consumed within 48 hrs to 5 days.
- Other characteristics from additional references include:
  - Underside of neck bruised with small puncture wounds evident; and Narrow scratch marks on ears, neck, forelegs or back (Smith 1945, Garner et al. 1976).

Bear

- Fawns killed by bears were completely consumed by time of recovery.
- Small bone fragments scattered throughout kill site.
- Large areas of matted down vegetation.
- No attempt to cover any remains.
- Tracks or scat within 5-10 m of kill site.
- Mortalities occurred in any habitat and had a scattered appearance compared to cat kill sites.
- Only young fawns were taken by bears and were consumed within 8-24 hrs.
- Other characteristics from additional references include:
  - Black bear canine punctures range from 0.6-1.3 cm in diameter (Vreeland 2002).

Coyote

- Punctures found in the head or neck, along with bruising and other related trauma of the neck and/or body. Occasionally, fawns attacked by coyotes died later from injuries or infection.
- Punctures approximately 0.3-0.5 cm in diameter and 2.9-3.5 cm apart.
- Enters through hind end, eats meat and internal organs, but avoids rumen and intestines. Rumen and intestines may be ripped out and opened but not consumed.
- Bones partially eaten or chewed leaving ragged edges on bones and tissue; carcass remains and blood scattered about the kill site.
- Coyotes may chew the nose, ears and hooves as well as the collar with an occasional attempt to bury it underground. No attempt to cache carcass.
- Tracks or scat found nearby, tracks approximately 6.4 cm long x 5.1 cm wide for the front foot and5.7 cm long x 4.4 cm wide for the hind foot, both with obvious claw marks in depression.
- Only young fawns were taken by coyotes and were consumed within 24-36 hrs.
- Other literature suggests the following additional characteristics:
  - Skull punctured or crushed (White 1973, Garner et al. 1976).
  - Underside of neck bruised without puncture wounds and broad scratches or bruises on back of neck and throat (Garner et al. 1976), or back (White 1973).
  - Viscera eaten including stomach and intestines if nursing (White 1973).
  - Uneaten parts may include long leg bones, hooves, and portions of the upper and lower jaw, especially tooth row (White 1973).

Appendix B. Mean date of capture, age in days at capture (±SE), and estimated date of birth for male and female black-tailed deer fawns for 2006, 2007 and 2008 in the Hoko Game Management Unit, Washington, USA.

Year		N	Mean Capture Date	Mean Age in Days	Mean Date of Birth
2006	Male	25	3-June	3.5 (0.6)	30-May
	Female	25	3-June	3.8 (0.6)	30-May
2007	Male	24	2-June	3.8 (0.5)	29-May
	Female	26	3-June	3.0 (0.5)	31-May
2008[a]	Male	28	28-May	3.7 (0.3)	25-May
	Female	38	29-May	4.3 (0.6)	25-May

[a] Indicates earlier mean date of birth in 2008 ($F_{5,163}$=8.27, P<0.0006)

Appendix C. Total numbers of single and twin black-tailed deer fawns including a breakdown of the number of twins captured, the twinning rate and the estimated number of fawns per doe between 2006 and 2008 in the Hoko Game Management Unit, Washington, USA.

Year	Total Fawns Captured	Singles Captured	Total Twins Captured	Number of Twins One Captured	Number of Twins Both Captured	Twinning Rate (%)	Estimated Number of Fawns per Doe
2006	50	12	38	14	24	76	1.7
2007	50	16	34	8	26	68	1.6
2008	66	18	48	3	44	72	1.6

Appendix D. Mean and standard errors (SE) of morphological measurements at capture and estimated morphological measurements at birth for male and female black-tailed deer neonates of 2006, 2007 and 2008 in the Hoko Game Management Unit, Washington, USA.

	2006				**2007**				**2008**			
	Male		Female		Male		Female		Male		Female	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Weight (kg)	4.5	0.23	3.9	0.17	4.4	0.21	3.9	0.22	3.9	0.14	3.9	0.20
Weight-at-birth (kg)	3.5	0.19	2.8	0.17	3.2	0.13	3.1	0.13	2.8	0.13	2.7	0.10
Length (cm)	61.9	1.30	61.0	0.93	61.7	1.11	61.0	0.80	59.8	0.87	60.6	0.85
Length-at-birth (cm)	58.8	1.14	57.7	0.78	58.2	0.96	58.5	0.69	56.7	0.80	56.8	0.67
Girth (cm)	36.3	0.71	34.7	0.62	34.5	0.62	33.7	0.57	33.0	0.42	32.8	0.60
Girth-at-birth (cm)	34.5	0.59	32.9	0.59	32.6	0.52	32.3	0.51	31.1	0.43	30.6	0.48
Hind foot (cm)	24.8	0.44	24.3	0.34	25.2	0.34	24.2	0.38	24.6	0.25	24.9	0.30
Hind foot-at-birth (cm)	23.6	0.37	23.1	0.32	23.8	0.30	23.3	0.32	23.3	0.24	23.4	0.22
Femur (cm)	15.3	0.48	14.7	0.48	16.2	0.62	15.5	0.47	14.0	0.43	13.6	0.29
Femur-at-birth (cm)	14.6	0.49	14.0	0.49	15.5	0.64	14.9	0.45	13.3	0.42	12.8	0.29
Condition Index	0.53	0.02	0.57	0.02	0.56	0.02	0.59	0.02	0.60	0.01	0.60	0.02
Condition-at-birth	0.59	0.02	0.64	0.02	0.63	0.01	0.64	0.01	0.67	0.01	0.69	0.01

Appendix E. Mean, standard errors (SE), and p-value of morphological measurements at capture and estimated morphological measurements at birth for Non-Hair Loss Syndrome (NHLS) and Hair Loss Syndrome (HLS) black-tailed deer neonates in the Hoko Game Management Unit, Washington, USA.

	Non-Hair Loss Syndrome Fawns (n=34)		Hair Loss Syndrome Fawns (n=26)		*P*
	Mean	SE	Mean	SE	
Weight (kg)	4.26	0.17	3.88	0.18	0.14
Weight-at-birth (kg)	3.23	0.11	2.99	0.15	0.23
Girth (cm)	34.87	0.48	33.80	0.62	0.19
Girth-at-birth (cm)	33.10	0.39	32.32	0.63	0.31
Condition index	0.56	0.01	0.59	0.02	0.13
Condition index-at-birth	0.62	0.01	0.64	0.02	0.19
Length (cm)	62.56	0.58	60.20	0.80	0.02
Length-at-birth (cm)	59.46	0.60	57.61	0.66	0.05
Hind foot (cm)	25.11	0.26	24.45	0.32	0.13
Hind foot-at-birth (cm)	23.90	0.24	23.44	0.31	0.25

Appendix F. Mean and standard errors (SE) of serum concentration values for Non-Hair Loss Syndrome (NHLS) and Hair Loss Syndrome (HLS) black-tailed deer neonates in the Hoko Game Management Unit, Washington, USA; and reference intervals of serum concentration values from deer ranges of mean values, elk means and standard deviations (SD), and cow ranges of values taken from various references denoted by superscripts.

	Black-Tailed Deer Neonates				Reference Intervals[a]		
	NHLS (n=28)		HLS (n=16)		Deer[b]	Elk[c]	Cow[d]
	Mean	SE	Mean	SE	Range	Mean (SD)	Range
Albumin (g/dL)	2.1	0.05	2.0	0.06	1.6-4.4	3.6 (0.7)	2.8-3.9
Alkaline phosphatase (U/L)	641	44.7	629	31.2	266-726[e]	224 (245)	18-153
Aspartate aminotransferase (U/L)	65	3.2	67	5.6	40-150[e]	67 (29)	45-110
Bilirubin (mg/dL)	0.7	0.04	0.6	0.05	0.5-1.1	0.6 (0.4)	0-0.8
Calcium (mg/dL)	9.3	0.24	9.4	0.28	9.1-12.8	9.5 (1.0)	8.4-11.0
Chloride (mmol/L)	100	0.8	99	0.6	100-110[e]	102 (4)	96-109
Cholesterol (mg/dL)	57	2.5	58	3.5	70.2-111.9	59 (22)	62-193
Creatine kinase (U/L)	91	13.7	185	110.3	20-400[e]		14-107
Creatinine (mg/dL)	0.8	0.04	0.8	0.08	0.4-2.0[e]	1.9 (0.7)	0.6-1.8
Gamma glutamyltransferase (U/L)	90	16.9	57	9.0	40-100[e]	44 (33)	4.9-26
Globulin (g/dL)	3.2	0.11	3.1	0.22	1.8-5.1	3.0 (0.8)	2.9-4.9
Glucose (mg/dL)	158	8.4	122	6.5	37.2-161.1	163 (51)	42-75
ID (SDH)	16.3	1.39	12.3	1.11			6.1-18
Iron (μg/dL)	344	24.8	334	36.7		172 (58)	
Magnesium (mg/dL)	2.5	0.07	2.3	0.07	2.2-4.0	1.93 (0.32)	1.7-3.0
Phosphorus (mg/dL)	10.5	0.29	9.4	0.34	5.2-11.2	7.6 (2.1)	4.3-7.8
Potassium (mmol/L)	5.4	0.14	5.2	0.20	3.4-5.0[e]	4.8 (0.6)	4.0-5.8
Protein (g/dL)	5.2	0.11	5.2	0.23	4.6-8.5	6.6 (0.8)	6.2-8.2

Appendix F (continued).

	Black-Tailed Deer Neonates				Reference Intervals[a]		
	NHLS (n=28)		HLS (n=16)		Deer[b]	Elk[c]	Cow[d]
	Mean	Se	Mean	se	Range	Mean (sd)	Range
Sodium (mmol/L)	145	1.1	143	0.6	132-156[e]	143 (4)	135-148
Total carbon dioxide (mmol/L)	16	0.7	17	0.9		24.9 (4.4)	
Urea nitrogen (mg/dL)	11	1.0	12	1.6	7.4-29.8	25 (8)	7.8-25
Total triiodothyronine (nmol/L)	3.4	0.10	3.3	0.10	1.42-2.08[g]		3.8 (0.62)[h]
Free triiodothyronine (pmol/L)	16.8	0.96	18.5	0.94	3.71-4.25[g]		
Total thyroxine (nmol/L)	149	2.8	150	4.2	90.03-146.47[g]	140.6 (13.6) ng/dL[f]	124 (30)[h]
Free thyroxine (pmol/L)	34	1.1	36	1.0	12.5-29.97[g]	3.0 (0.21) μg/dL[f]	
Insulin-like growth factor-1 (nmol/L)	40	1.5	40	2.9		273.7 (9.72) ng/mL[f]	13.6 (1.82)[h]

[a] Reference intervals are based on published data samples from adults.
[b] Deer References are taken from 3 sources: Values from mule or black-tailed deer as compiled in Anderson (1981); and see superscripts e and g.
[c] Elk References are taken from 2 sources: International Species Information System; and see superscript f.
[d] Cow references are taken from the Merck Veterinary Manual (Kahn 2007); and see superscript h.
[e] Specific values from white-tailed deer from Seal et al. (1981) as cited from the International Species Information System.
[f] Specific values from elk calves in autumn/spring from Cook (2002).
[g] Specific values from adult mule deer showing ranges of means for control and treatment deer from Bishop et al. (2009).
[h] Specific mean and standard error values from calves of a control group at 32 hours of age from Kirovski et al. (2008).