AN ABSTRACT OF THE THESIS OF

Jason A. Robison for the degree of Master of Science in Wildlife Science presented on June 14, 2007.

Title: Transmission of the Chewing Louse, *Damalinia (Cervicola) sp*., from Columbian Black-tailed Deer *(Odocoileus hemionus columbianus)* to Rocky Mountain Mule Deer *(Odocoileus hemionus hemionus)* and its Role in Deer Hair-loss Syndrome.

Abstract approved:

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Bruce E. Coblentz

The potential for Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) to host exotic chewing lice (*Damalinia (Cervicola) sp*.) believed to cause deer hair loss syndrome in Columbian black-tailed deer (*Odocoileus hemionus columbianus*), was investigated in captive deer held in pens at E.E. Wilson Wildlife Area, Corvallis, Oregon from March 2004 to May 2005. It is believed that the exotic chewing louse causes a hypersensitivity reaction which results in pruritis, excessive grooming and removal of pelage. The potential transmission of *D. (Cervicola) sp.* from affected black-tailed deer to Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) was unknown. To answer this question, unaffected mule deer were both experimentally infested (inoculated) with *D. (Cervicola) sp*., and held in direct contact with (*D. (Cervicola) sp.*) infested black-tailed deer. Grooming behavior, louse abundance, and clinical signs were monitored and recorded monthly for 14 months. The exotic louse *D. (Cervicola) sp.* was identified on six mule deer following treatment, and evidence of louse reproduction (eggs, and nymphs) was present. A strong seasonal pattern in

louse abundance was observed in all groups and within subspecies, and was correlated with date, with higher louse abundances occurring from April-June 2004, and March-May 2005; lower numbers occurred from August 2004 through February 2005. Eggs, nymphs and adult lice were found on all body regions, and abundances varied by month. Mule deer held in direct contact with infested black-tailed deer showed slight increases in frequency of grooming behavior from January to April 2005 in conjunction with increasing louse abundance and grooming bout duration. Six mule deer developed small localized patches of hair-loss following treatment; two had hair loss throughout much of their sides and rump. Eight black-tailed deer showed signs of recovery at the end of the study. It was concluded that transmission of the exotic louse *D. (Cervicola) sp.* from infested black-tailed deer to non-infested mule deer is possible when the two species are held in direct contact. In addition, there is a link between the irritations caused by the infestation of *D. (Cervicola) sp.*; grooming response; and loss of hair in both black-tailed deer and mule deer.

Transmission of the Chewing Louse, *Damalinia (Cervicola) sp*., from Columbian Black-tailed Deer *(Odocoileus hemionus columbianus)* to Rocky Mountain Mule Deer *(Odocoileus hemionus hemionus)* and its Role in Deer Hair-loss Syndrome.

by

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APPROVED:

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Head of the Department of Fisheries and Wildlife

Dean of the Graduate School

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

Jason A. Robison, Author

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gained valuable experience from this project and good luck with all of your future endeavors. I look forward to one day working with all of you again.

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Transmission of the Chewing Louse, *Damalinia (Cervicola) sp*., from Columbian Black-tailed Deer *(Odocoileus hemionus columbianus)* to Rocky Mountain Mule Deer *(Odocoileus hemionus hemionus)* and its Role in Deer Hair-loss Syndrome.

1 INTRODUCTION

Hair-loss syndrome (HLS) is a newly described disease affecting Columbian black-tailed deer (*Odocoileus hemionus columbianus*) (BTD) populations in the Pacific Northwest (Foreyt et al., 2004; Bildfell et al., 2004; and Bender and Hall, 2004). The first observations of HLS in BTD occurred near Bangor Submarine Base, in the Puget Sound area of west-central Washington (USA), in 1995 (Bender and Hall, 2004). Since these early observations, HLS has spread southward, and has been documented throughout western Oregon. The current affected area ranges as far north as the Canadian border and as far South as the California border (USA) (Jack Mortenson, Personal communication). Clinical signs of HLS have been reported in all habitat types including agricultural areas below 610 meters in elevation and forested areas as high as 1400 meters. Clinical signs (darkening of the dorsal hair coat; progressing to yellow - white discoloration of pelage on the rump, sides and back; hair loss; raw skin; emaciation; and diarrhea) may occur in late Fall and Winter (November-December) and progress through late Spring (April-May). According to Bender and Hall (2004); etiological studies at the Washington Animal Disease Diagnostic Laboratory (Pullman, Washington, USA) and the Oregon State University School of Veterinary Medicine (Corvallis, Oregon, USA) have been inconclusive. It is possible that HLS is the result of hypersensitivity caused by infestations of adult lung worm (*Dictyocaulus sp*.) and larval muscle worm (*Parelaphostrongylus odocoilei*) in conjunction with a nutritional deficiency. A study by Foreyt et al., (2004) found by reducing endoparasite loads with antihelminthic drugs, BTD affected with HLS were able to re-grow hair and increase weight. A study by Bildfell et al. (2004) also found large internal parasite loads in most deer examined. However, they suggested that the proximate cause of HLS might be due to the large loads of chewing lice consistently found on clinically ill animals. In addition Bildfell et al. (2004) found an average of

133 adults and nymphs per cm^2 on some BTD in Oregon, estimating total lice numbers to be in the tens of thousands. Thousands of chewing lice were also observed on BTD with clinical signs of HLS in Washington Foreyt et al. (2004). No previous scientific reports have documented lice numbers of this magnitude from BTD populations.

Only two species of Mallophaga (Chewing Lice) have been previously described from deer in Oregon and Washington. *Damalinia (Tricholipeurus) lipeuroides (DTL)*, was described in white-tailed deer (*Odocoileus virginianus*)(WTD) (Zimmermann, 1980) and mule deer (MD) (*Odocoileus hemionus hemionus*) (Anderson, 1962; Samuel and Trainer, 1971), and *Damalinia (Tricholipeurus) parallela (DTP)* was described on WTD and MD (Emerson and Price, 1975) and BTD (Hopkins, 1960). Bildfell et al. (2004) reported that lice samples from infested BTD were identified by James W. Mertins, Ph.D., United States Department of Agriculture, National Veterinary Services Laboratory,, as an undescribed species of chewing louse within the genus and sub-genus *Damalinia Cervicola* (Lyal, 1985). Prior to this identification, the sub genus *Cervicola* had only been reported in Old-World (Asian) cervids and African bovids (Price et al., 2003; Lyal, 1985). Genetic and morphological analysis has shown a distinct difference between known chewing lice species from the Pacific Northwest and this exotic species (Jack Mortenson, Personal communication). In addition genetic similarities may exist between this newly identified exotic louse species, and *D. (Cervicola) nippon* (Emerson and Price, 1973) a parasite of Japanese sika deer (*Cervus nippon*) (Jack Mortenson, Personal communication). It is likely that D. *(Cervicola) sp.* are similar to other chewing lice species of the same genus, They live in close contact with their hosts tissues and feed on lipid secretions, loose scurf, and bacteria. As a result of this method of feeding, the host is presented with a range of secretory, excretory, and cuticular antigens. Similar antigens have been known to cause hypersensitivity in sheep infested with *D.* (*Bovicola) bovis* (James and Moon, 1998).

The life cycle of *D. (Cervicola) sp.* is likely similar to many species of the same genus. There are three distinct stages; egg (nit), nymph, and adult. The eggs are

cemented to the hair shaft base and hatch in 1-2 weeks (Price and Graham, 1996). Nymphal development is completed approximately 2 weeks after hatching. In most Mallophagan lice, three instar nymphal stages are achieved before adulthood (Price and Graham, 1996). The total time from egg to adult is approximately 30 days. Unlike native cervid lice in the genus *Damalinia*, this particular species appears to reproduce asexually through parthenogenesis. Bildfell et al. (2004) reported that after examinations of thousands of lice samples from BTD, no male lice were identified.

There is no known stage in the Mallophagan life cycle that is especially adapted for dispersal; the only obvious transmission of lice is through direct contact with infested hosts (Ryder, 1967). However, common areas such as bedding areas and feeding grounds may provide opportunities for louse transmission (Price and Graham, 1996), and lice were commonly found in the bedding material in pen facilities used in this study. Since deer are polygynous, breeding activities may also provide for transmission to multiple individuals within various sub-populations.

Grooming behavior is critical in socialization among cervids (Miller, 1971). Many studies have noted the importance of grooming behavior on initiation of parent-offspring relationships at parturition (Forand and Marchinton, 1989; Golley, 1957; Halford and Alldredge, 1975). Frequent allogrooming among matrilineal groups may also promote the transmission of the lice.

All known members of the genus *Damalinia* exhibit a distinct seasonality in abundance (Samuel et al., 1971; James, 1999; and Bildfell et al., 2004) with numbers peaking during the winter months and decreasing during the summer months. A similar pattern is observed in the occurrence of HLS symptoms, and there appears to be a link between the occurrence of HLS and changes in abundance of *D. (Cervicola) sp.*

I hypothesize that this non-indigenous louse is causing a hypersensitivity reaction in BTD and that this hypersensitivity results in stimulation of pruritic behaviors such as excessive licking, biting, and scratching. James and Moon (1998)

reported that similar behaviors led to the removal of wool in sheep infested with *D. (Bovicola) bovis*.

Unlike native host-parasite relationships, where a presumed natural balance between parasite abundance and host health occurs, a naïve host has little to no protection against the impacts of non-native parasites. This may explain the severity and prevalence of infestations in BTD populations, and the excessive response. The identification of this exotic louse may also provide some explanation for the sudden occurrence of HLS in BTD. Prior to 1995 widespread outbreaks of hair-loss had not been recorded by biologists, tribal elders, or hunters (Bildfell et al., 2004).

Currently, there have been no verified occurrences of HLS in wild MD populations in Oregon or Washington; however the potential of transmission from BTD to MD may be high in areas of the Cascade Mountains (the Cascades), where summer ranges of the two subspecies overlap. Consequently, the goals of this study were to determine if *D. (Cervicola)* can transmit from BTD to MD and to determine the role of *D. (Cervicola)* sp. in HLS development. We used the following objectives to achieve those goals: (1) determine the presence or absence of *D. (Cervicola) sp.* on MD following two louse treatments; (2) quantify abundance, persistence, and spatial distribution of *D. (Cervicola) sp.* on infested deer; and (3) determine a chronology of HLS progression in captive individuals. We also assessed the potential for recovery in captive BTD.

2 METHODS

2.1 Study Site

This study was conducted for 15 months from March, 2004 to May, 2005 at the E.E. Wilson Wildlife Management Area (EEW), a 1600 acre wildlife area managed by the Oregon Department of Fish and Wildlife located in Benton County, Oregon, USA ten miles north of Corvallis on Highway 99W (Figure 1).

Historically, the site was used as a pheasant rearing facility. Existing pheasant pens were modified into five field pens (Figure 2). Each pen had a woven wire perimeter fence with polyester shade cloth attached on the inside of the fence to reduce visibility and act as a safety barrier for stressed animals. A similar perimeter fence, with the exception of the shade cloth, was constructed around the outside of pens 1 and 2 and 3 through 5 to prevent escape in the event of internal fence failure. Separate research buildings, squeeze chutes, and food /water delivery systems were constructed for each pen (Figure 3)

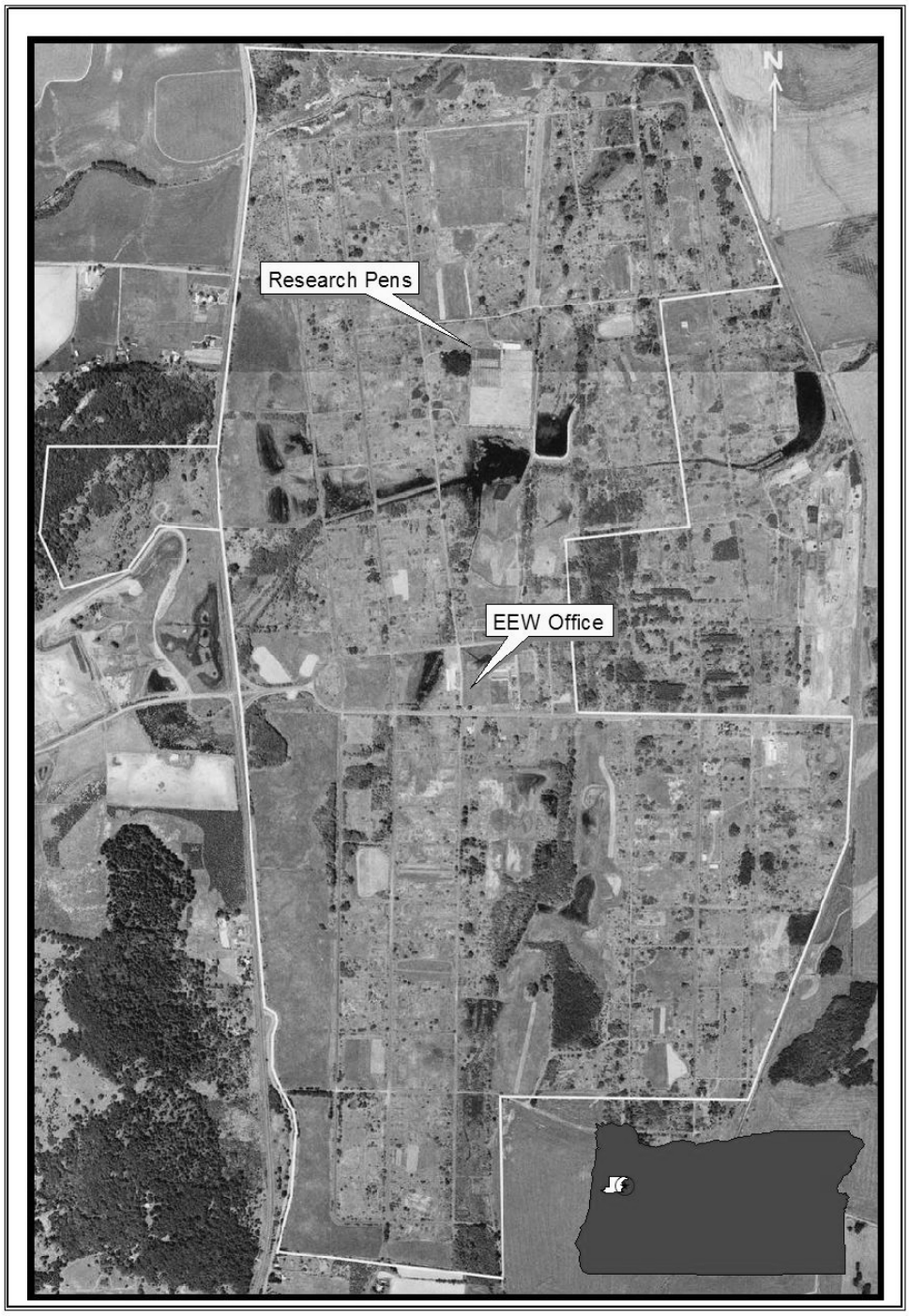

Figure 1. Location of HLS research pens at EEW Management Area, Benton County, Oregon.

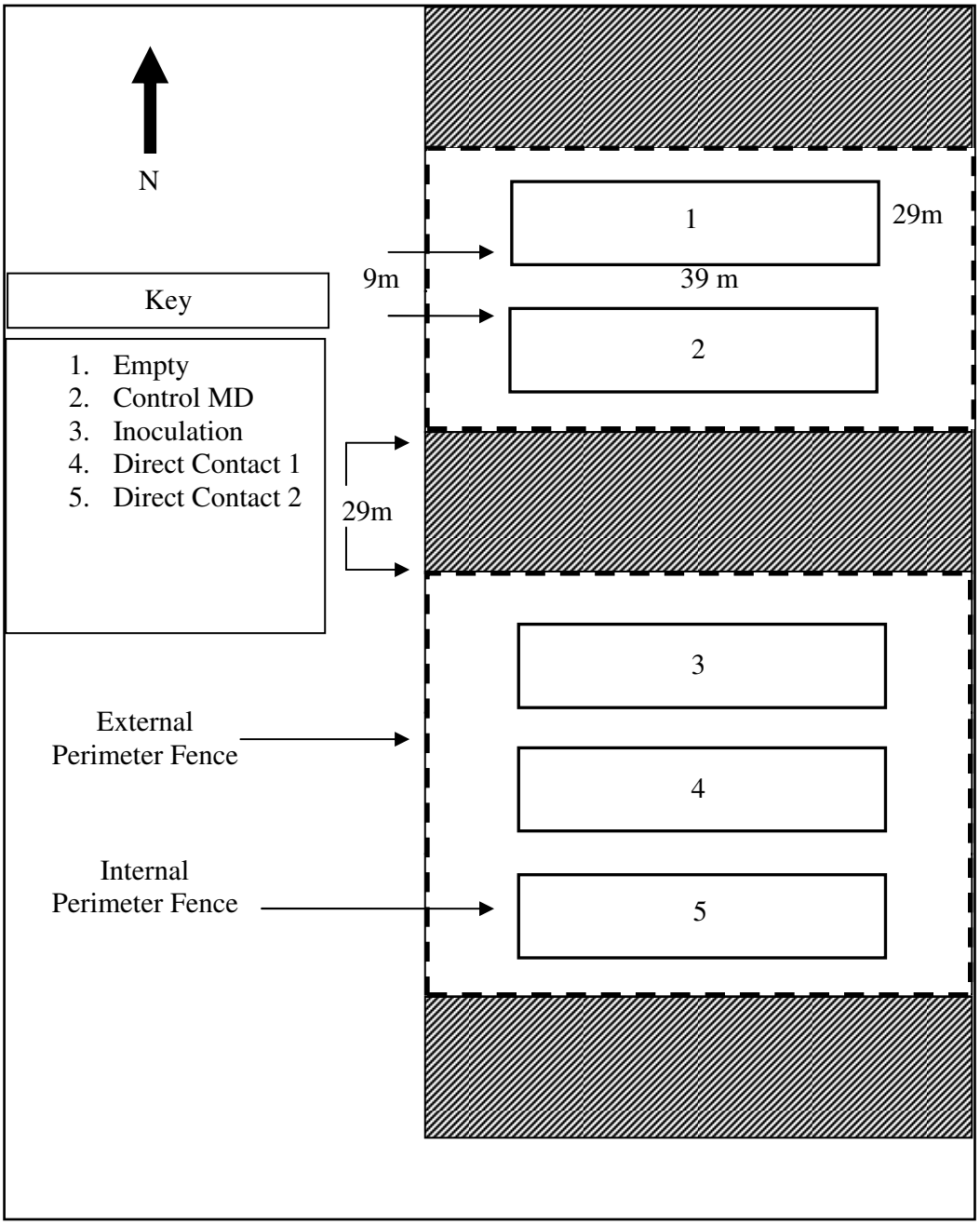

Figure 2. The layout of research pens at EEW Wildlife Management Area. Each pen was 29 meters wide by 39 meters long. All pens were 9 meters away from the closest adjacent pen. A distance of 29 meters separated the external perimeter fences of pens nos.1 and 2 and pens nos. 3, 4, and 5.

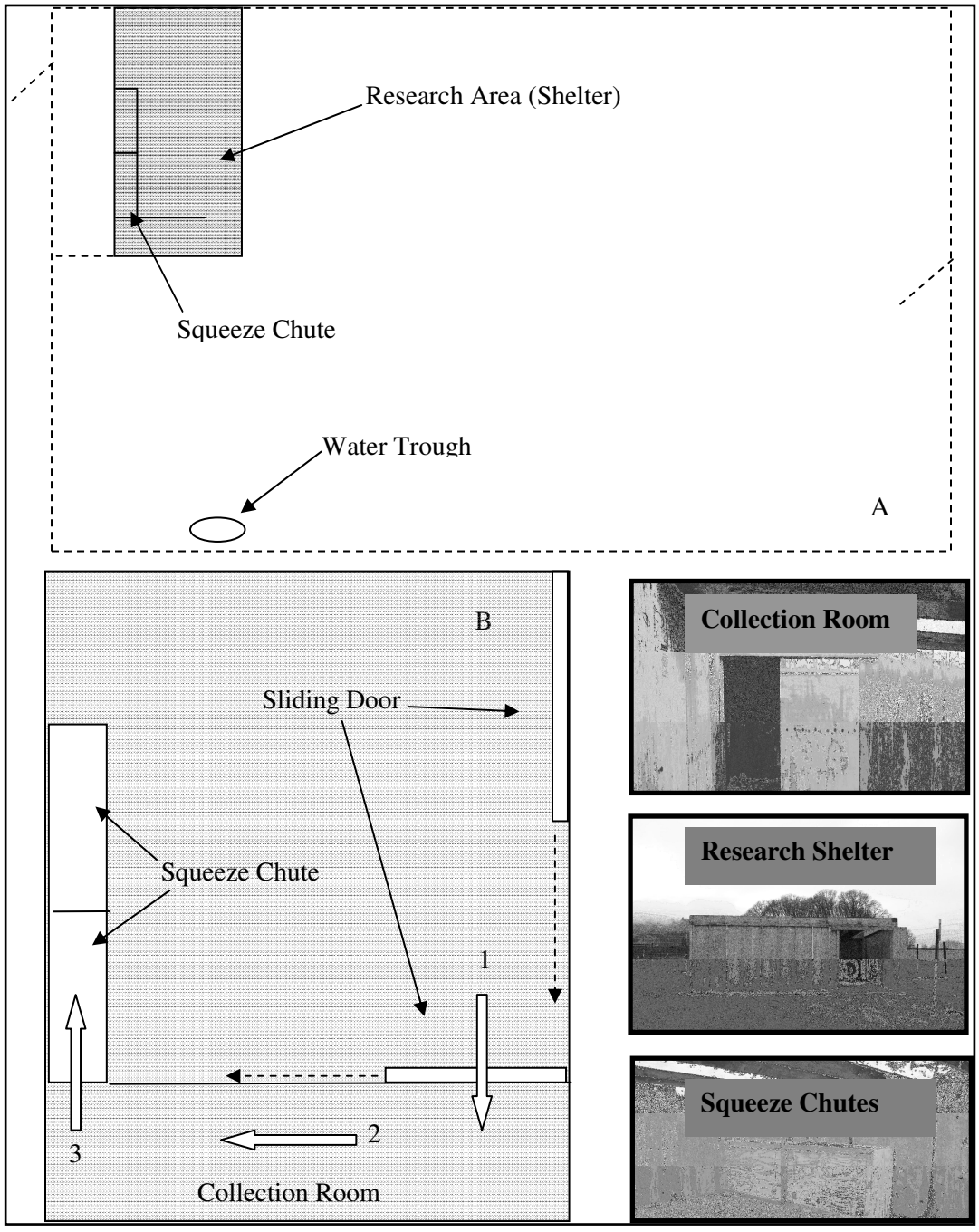

Figure 3. (A) Individual deer pen layout and (B) internal design of research shelters at EEW Wildlife Management Area. The ⇦ symbol represents the direction taken by a deer as it is moved trough the research facility. The numbers (1-3) represent the order in which each deer is moved.

2.2 Deer Capture

Prior to capture, we subdivided the entire state into three areas based on the location of known HLS cases. These areas included the: endemic area, expansion area, and the free area (Figure 4). The endemic area was the area with the highest potential risk of hair-loss syndrome, and included all areas less than or equal to 1400 meters in elevation (the highest known occurrence of hair-loss syndrome), expanding west of the cascades to the Pacific Ocean, north to the Washington border, and south to the California border. This area was chosen for capture of BTD. The expansion area was defined as all areas up to 200 km east of the cascade peaks, north to the Washington border, and south to the California border. This area was designated based on known overlap between BTD and MD summer habitats, as well as reports of unconfirmed cases of HLS in MD from that area (Jack Mortenson, Personal communication). The free area was defined as all areas east of the expansion zone to the Idaho border, north to the Washington border, and south to the Nevada border. This area had the least potential risk of exposure to affected individuals and was chosen as the ideal capture area for HLS free MD.

A total of 27 MD and 16 BTD fawns, approximately 9-months of age, were captured for this study (Oregon permit # 003-04). An initial 18 MD fawns were captured on February 4th (n= 5), February 11th (n=5), and February 19th (n=8), 2004, at two feed sites located in the Elkhorn Wildlife Management Area in Baker County, Oregon (Table 1). An additional 9 MD were captured on 6 April, 20 May, 28 May, and 24 July, 2004 as replacements for initial mortalities (Table 2). Two groups of BTD deer fawns (n=16) were captured at multiple capture sites in Lane, Lincoln, and Benton Counties, Oregon. BTD capture occurred during 11-26 March, 2004 and 13 January and 18 February, 2005. A summary of capture locations, methods, and demographics for the initial 34 deer used in the study is presented in Table 1.

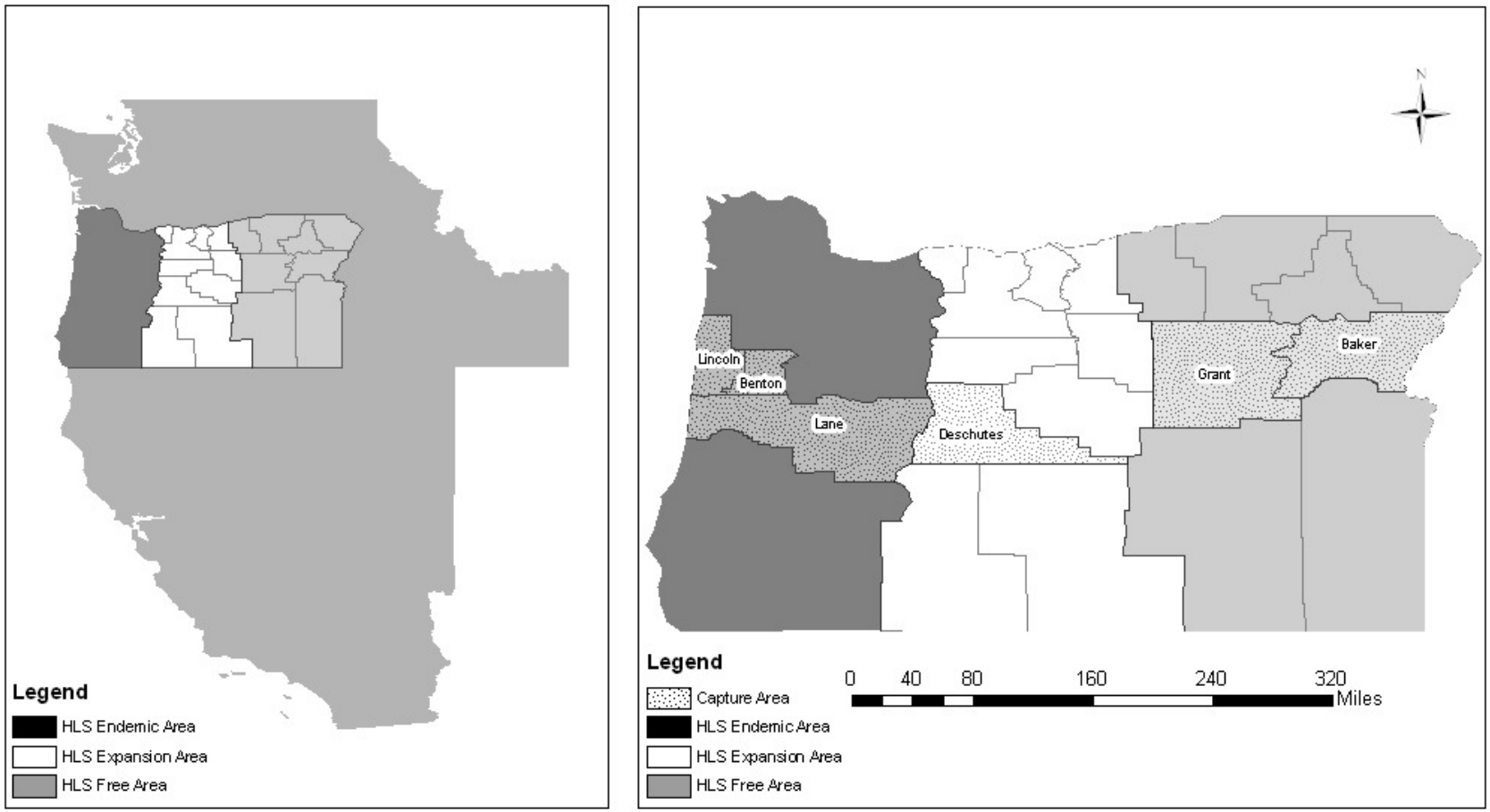

Figure 4. Oregon counties in which deer were captured within the HLS free zone, HLS expansions zone, and HLS endemic zone.

Table 1. Capture summary of initial mule deer and black-tailed deer used in the study. (Continued on next page)

Date Captured	ID #	Sex	Species	Infested	County	TRS	Capture Method*
2/19/04	B408	F	MD	No	Baker	7S 38E 28	CI
2/11/04	B410	F	MD	No	Baker	10S 39E 1	CT
2/11/04	B412	M	MD	No	Baker	10S 39E 1	CI
2/11/04	B419	F	MD	No	Baker	10S 39E 1	CI
2/11/04	B422	M	MD	No	Baker	7S 38E 28	CI
2/11/04	B424	M	MD	No	Baker	7S 38E 28	CT
2/19/04	G32	M	MD	No	Baker	10S 39E 1	CT
2/19/04	G40	M	MD	No	Baker	10S 39E 1	CI
2/19/04	G45	M	MD	No	Baker	7S 38E 28	CI
2/4/04	O269	F	MD	No	Baker	10S 39E 1	CT
2/4/04	O270	M	MD	No	Baker	10S 39E 1	CT
2/4/04	O271	M	MD	No	Baker	10S 39E 1	CT
2/4/04	O272	M	MD	No	Baker	10S 39E 1	CT
2/4/04	O273	F	MD	No	Baker	10S 39E 1	CT
2/24/04	O274	F	MD	No	Baker	10S 39E 1	CT
2/19/04	P216A	M	MD	No	Baker	7S 38E 28	CI
2/19/04	P221	F	MD	No	Baker	7S 38E 28	CI
2/19/04	P224	M	MD	No	Baker	7S 38E 28	CI
3/11/04	P223	F	BTD	Yes	Lincoln	ND	CI
3/12/04	G33	F	BTD	Yes	Benton	11S 6W 7	CI
3/13/04	P225	F	BTD	Yes	Lincoln	13S 11W 19	CT
3/15/04	G51	M	BTD	Yes	Benton	11S 6W 7	CI
3/17/04	G39	M	BTD	Yes	Benton	11S 5W 19	CT
3/23/04	G38	F	BTD	Yes	Benton	11S 6W 7	CI
3/23/04	G58	F	BTD	Yes	Lane	16S 1W 17	CT
3/25/04	G46	F	BTD	Yes	Lane	16S 1W 17	CT

**CI = Chemical Immobilization, CT = Clover Trap, ND = No data*

(Continued from Previous Page)

Date Captured	ID #	Sex	Species	Infested	County	TRS	Capture Method*
4/6/04	P202	F	BTD	Yes	Lincoln	13S 11W 19	CT
4/9/04	P222	F	BTD	Yes	Lincoln	14S 10W 33	CI
1/13/05	G59	F	BTD	Yes	Benton	11S 7W 6	CI
1/16/05	G46	M	BTD	Yes	Benton	11S 6W 7	CI
1/27/05	G37	M	BTD	Yes	Benton	11S 6W 7	CI
1/27/05	G38	M	BTD	Yes	Benton	11S 6W 7	CI
2/17/05	G36	F	BTD	Yes	Benton	11S 5W 17	CI
2/18/05	G19	F	BTD	Yes	Benton	11S 5W 17	CI

**CI = Chemical Immobilization, CT = Clover Trap*

Table 2. Capture summary for replacement mule deer used in the study.

Date Captured	**ID #**	**Sex**	**County**	**TRS**	***Capture Method**
5/28/04	O-275	M	Grant	13S 31E 1	CI
5/28/04	0-282	M	Grant	13S 31E 1	CI
7/24/04	G-35A	F	Grant	13S 31E 1	HC
5/20/04	P-11	F	Deschutes	ND†	CI
5/20/04	P-12	F	Deschutes	ND†	CI
5/20/04	P-13	F	Deschutes	ND†	CI
5/28/04	R-418	M	Grant	13S 31E 1	CI
4/6/04	P-216	M	Grant	13S 31E 1	CI
5/28/04	B-411	F	Grant	13S 31E 1	CI

*†ND= No Data, *CI = Chemical Immobilization, HC=Hand Captured*

Deer were captured using single gate collapsible Clover traps (Figure 5), and anesthetized. Clover traps were used on MD feeding sites during periods of dense snow pack, or at private residences. Alfalfa hay was used as an attractant for MD in snow covered feed sites in Baker County, and apples were used as attractant for BTD in Benton, Lincoln, and Lane counties.

Figure 5. A male mule deer fawn captured in a collapsible clover trap at the Elk Creek capture site, Baker County, Oregon.

Deer were anesthetized using 2.0 - 4.4 mg/kg Telazol®, plus 1.0 - 2.2 mg/kg xylazine (100 mg/ml) intramuscularly (Kreeger et al., 2002). A 22-caliber pneudart® rifle was used to remotely deliver a 1-2cc barbed pneudart® with a 2.5-3.8 cm needle from a distance of 10 to 36 meters. Deer closer then 9 meters were anesthetized using a CO2-powered Dan-inject® pistol. Incomplete anesthesias were supplemented using 2.2 mg/kg ketamine HCL injected intravenously. Xylazine was antagonized with 4.0 mg/kg tolazoline (100 mg/ml), or 0.125 mg/kg yohimbine injected intravenously.

Following live capture and anesthesias, all deer were hobbled and placed in sternal recumbency. To protect the eyes from drying or physical damage and to decrease visual stimuli; eye ointment and a blindfold were applied. If darted, the dart was removed and a topical antibacterial ointment was applied to the wound. An intramuscular injection of penicillin (20 units/kg) was given when dart head (portion of the dart behind the needle) penetrated beyond the skin surface. To reduce capture myopathy, one ml of vitamin-B and selenium were also given. During anesthesias, respiration, pulse, response to auditory and visual stimuli, and body temperature were monitored at 2-minute intervals. A pulse-oximeter was used to monitor blood oxygen levels. All deer were examined for existing wounds and treated if deemed necessary. In addition, the genders of all deer were recorded prior to being tagged with a color coded numeric ear tag denoting the designated research group. Total handling time was 30 and 60 minutes per animal.

Following capture, all deer were placed in ventilated transport crates and transported to EEW. Water was provided in the form of an ice block during transportation. Routine checks were done every hour for long distance transports and every 15 minutes for shorter trips. Upon arrival to the research facility, MD were assigned to one of four pens corresponding to their colored ear tag (ear tag numbers and colors were selected at random during capture) (Table 3). All deer were run through the squeeze chutes and sampled for lice prior to experimental treatment. Lice samples were sent to the United States Department of Agriculture, National Veterinary Services Laboratory (NVSL), Ames, Iowa for identification.

Table 3. Ear tag colors, corresponding pen numbers and treatment groups for black-tailed deer and mule deer.

Tag Color	Pen #	Treatment Group
Orange	2	Control*
Blue	3	Inoculation*
Purple	4	Direct Contact
Green	5	Direct Contact

*Mule deer only.

2.3 Experimental Treatments/Study Design

This study was a modified block design, in which two treatments were applied to two separate groups of MD. A control group was also used as a baseline for comparisons with treatment groups. Sample sizes for each group were balanced (n=6) to optimize precision of treatment comparisons, and to ensure independence of estimated treatments effects (Ramsey and Schafer, 2002). In addition randomization in capture ensured that body conditions, weights, and genders of deer captured were representative of the entire population. For this study the population we were investigating was MD and BTD less than 1 year of age.

Six MD (3 males, 3 females) were housed in pen number two and designated as a control pen. Deer in this group were kept isolated from all other groups for the duration of the study, and were used for baseline comparisons of louse type, louse abundance, body condition, and grooming behavior.

Six MD (3 males, 3 females) were housed in pen number three and designated as the inoculation treatment pen. The deer in this pen were each experimentally inoculated with 150 lice removed from BTD in January, 2005. The purpose of this group was to verify that clinical signs of HLS were directly related to the presence or absence of *D. (Cervicola) sp.*.

The final two holding pens (4 and 5) were designated as direct contact treatment pens. MD in pens 4 (2 male, 1 female) and 5 (3 males) were exposed directly to 3 affected BTD (Figure 6) over two different time periods; April 4, 2004 to December 18, 2004, and January 27, 2005 to May 15, 2005. We used two different exposure periods for this group because louse densities on BTD during the first exposure period failed to increase after the first summer and limited numbers of lice were available for transmission to MD. BTD from the first exposure period were relocated to pen 1 at the onset of the second exposure period. Following relocation, BTD in pen 1 were monitored for signs of recovery (increased weight, decreased louse abundance, and decreased hair-loss) for the duration of the study.

Figure 6. A hair-loss syndrome affected black-tailed deer (left) feeds near a mule deer (right) in the direct contact group, research pen #5.

All research deer were fed a combination of free choice alfalfa pellets and mixed alfalfa/orchard grass hay. Pellets were fed at a ration of approximately 900 grams per 45kg of deer body weight per day (recommended by manufacturer). Hay was fed at a ration of approximately 3600 grams per 45 kg of deer body weight per day as supplemental roughage. All deer were given an antihelminthic (fenbendazole) in the form of treated alfalfa pellets once every three weeks to control for endoparasites.

In order to prevent cross contamination between pens, deer were fed in numeric order starting in the control pen and ending in the treatment pen (#5). Researchers wore rubber boots and disposable Tyvek® coveralls during feeding; new coveralls or clothing was worn each day. A solution of Nolvasan ® disinfectant was used to clean boots after every feeding on each day. Deer were only fed once daily. Bedding areas and water troughs were examined and cleaned once monthly. Control and treatment groups were cleaned on alternate days, to avoid any contamination.

For human and animal safety, all male deer were castrated to reduce aggressive behavior and their antlers were removed. The treatment of all research deer conformed to or exceeded animal health and welfare guidelines approved by the Oregon State University, Institutional Animal Care and Use Committee (IACUC) (ACUP # 2965).

2.4 Data Collection

2.4.1 Routine Anesthesia

All deer were routinely anesthetized at 3-4-week intervals from April 2004 to May 2005. Deer were driven into squeeze chutes where immobilizing drugs were administered intramuscularly in the caudal thigh via hand injection (remote darting equipment was used in some instances). Deer were immobilized using 2.0 - 4.4 mg/kg Telazol, plus 1.0 - 2.2 mg/kg xylazine (100 mg/ml) intramuscularly or 100-150 mg/kg medetomidine intramuscularly. Incomplete anesthesias were supplemented using 2.2

mg/kg ketamine intravenously (Jack Mortenson, Personal communication). The xylazine was antagonized with 4.0 mg/kg tolazoline (100 mg/ml) intravenously, or .125 mg/kg yohimbine intravenously. Medetomidine was antagonized using 0.35 mg/kg atipamezole intramuscularly. All referenced drug dosages were taken from Kreeger et al., (2002). Once unconscious, the animal was removed from the squeeze chute and eye ointment, blinders, and hobbles were applied. Respiration, pulse, response to auditory and visual stimuli, and body temperature were monitored and recorded at two-minute intervals.

2.4.2 Weights, and Louse Abundances

While deer were anesthestized, measurements of weight, and louse abundance were recorded. Weights were recorded to the nearest .25 kg on a hanging scale. Louse abundance was measured by counting nits, eggs, and adult lice in10cm hair partings (Figure 7) on 4 body regions (head/neck , back, rump, and groin/belly) (Figure 8). Louse counts were performed on both the left and right sides of each deer. In addition, louse samples were removed from infested MD post treatment and sent to NVSL for taxonomic identification.

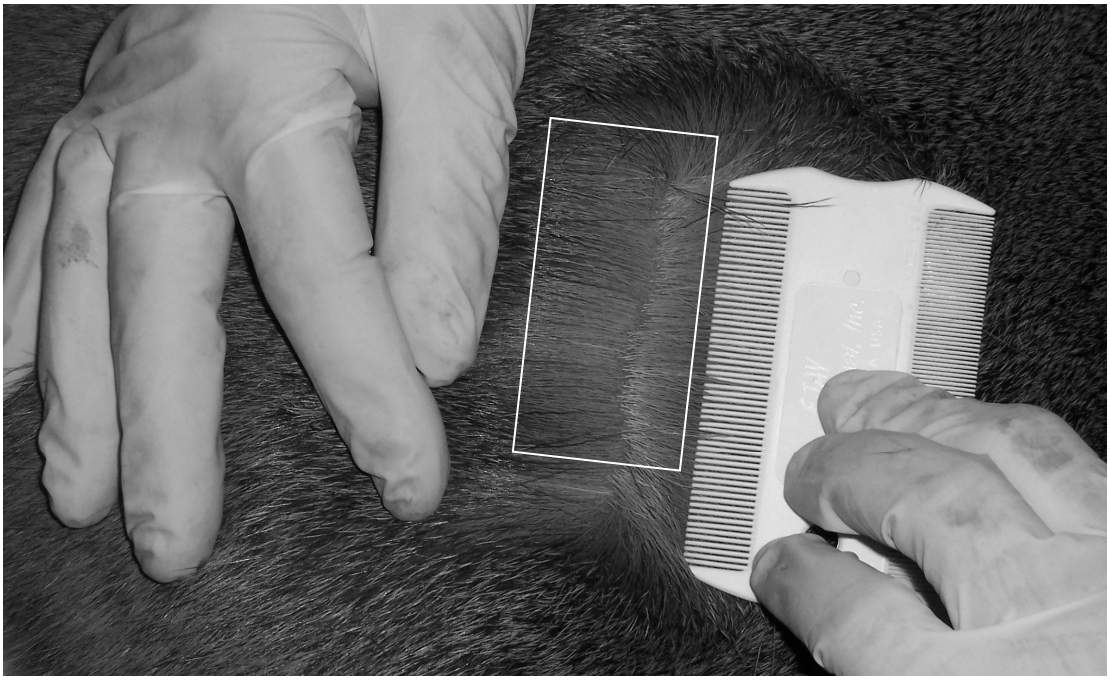

Figure 7. Hair parted on a mule deer using 10cm louse comb.

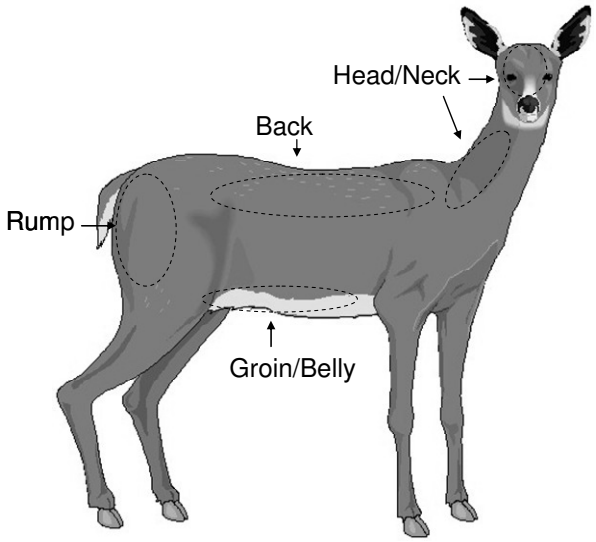

Figure 8. Body regions on deer where louse abundance was examined.

2.4.3 Hair loss Score

A hair-loss score from 0 to 5 (Table 4, Figure 9) was assigned to each animal based on the observer's assessment of the degree of hair-loss. In addition, photographs of the back, sides, and groin were taken from each deer for visual reference.

Table 4. Description of hair-loss scores assigned to study deer at the E.E. Wilson Wildlife Management Area.

Area.

Score	Description
0	No hair-loss
1	Hair-loss on %10 of body, localized to ONE small (<10cm^2) area on one side
2	Hair-loss on 20-30% of body, small (<10cm^2) patches on both sides
3	Hair-loss on 40-60% of body, large (>10cm^2) patches on both sides
4	Hair-loss on 70-80% of body
5	Hair-loss on 90% of body, bald raw skin

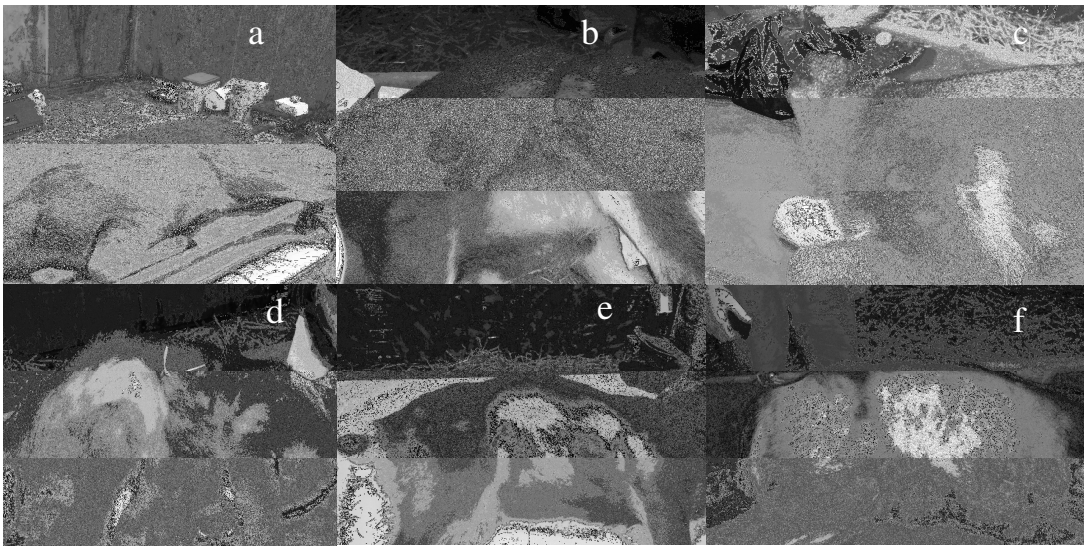

Figure 9. Photo representation of hair-loss scores assigned to mule deer. (a) Hair-loss Score (HLS) =0, (b) HLS=1, (c) HLS=2, (d) HLS=3, (e) HLS= 4, (f) HLS = 5.

2.4.4 Daily Grooming Behavior

Grooming behavior and time spent grooming were recorded once daily for all MD for four months from 8, January – 18, April 2005. Grooming behavior and time spent grooming were recorded during a series of 10-minute focal animal samples when one individual was followed continually. Deer were identified individually by ear tag number and color. Observation periods occurred following morning feedings, allowing observers to get closer to individual animals. Individual grooming (a grooming bout) was recorded whenever licking, biting, scratching, or shaking, occurred. The duration of each bout was also recorded.

2.4.5 Mortality and Deer Replacement

Deer that died during the project were sent to Oregon State University (OSU), College of Veterinary Medicine Diagnostic Laboratory (CVMDL) in Corvallis, Oregon (USA) for necropsy. Replacement deer were added when the sample size of any treatment group fell below three. All surviving deer at the end of the study were

euthanized, using phenobarbital given intravenously, and were subjected to necropsy by staff at OSU CVMDL.

2.5 Data Analysis

Statistical analysis was performed using the S-plus statistical Software ® (Insightful Corporation), and Microsoft Excel® (Microsoft Cooperation). Except were noted, a significance level of α=0.05 was selected a priori for all analytical statistics.

2.5.1 Louse Identification

In order to determine the transmission of *D. (Cervicola) sp.,* pre - and post-treatment louse samples were identified and compared for all MD in the direct contact treatment. Post-treatment samples for direct contact MD were also compared to samples taken from the control group in order to rule out possible environmental transmission (transmission from source other than host-to-host contact). In addition, evidence of louse reproduction was also assessed post-treatment by determining if there were eggs and nymphs found on each MD infested with *D. (Cervicola) sp.*. Eggs and nymphs were not keyed to species.

2.5.2 Louse Abundance and Spatial Distribution

Single factor analysis of variance (ANOVA) was used to determine if there was a significant difference in the mean louse abundance for each louse type, by research month. Arithmetic mean total abundances of nits, nymphs and adult lice were calculated for each of the four body regions (head, back, rump, and groin) on all research MD and BTD by adding the total number of lice sampled in each region by the total number of samples (n=2, left and right sides).

To determine if there were effects of treatment on louse abundance, arithmetic mean monthly louse abundance and mean total louse abundance were compared between research groups using ANOVA procedures (Ramsey and Schaffer, 2002).

Arithmetic mean monthly louse abundance was calculated by adding the mean louse abundance for all MD or BTD in each group on any given month, and dividing by the total number of MD or BTD in each pen. The mean total abundance was calculated by adding all mean monthly nymph and adult lice abundances for each treatment group.

A percentage of abundance was also calculated for each louse life stage to determine if different louse life stages occupied different body regions at different times of year. The percentage of abundance was calculated on each of the four body regions by dividing the mean number of eggs, nymphs, and adults by the total number of eggs, nymphs, and adults from all samples. Additionally, the effect of gender on louse abundance, mean monthly louse abundance for male and female deer were calculated and compared using ANOVA procedures.

2.5.3 Weights

Arithmetic mean monthly deer weights for BTD and MD in all treatment groups were calculated and compared for treated and untreated (control) deer, using ANOVA procedures. In BTD, differences in starting weights between the first group and second group were assessed using ANOVA procedures. Differences between genders were also assessed using ANOVA. Correlations between weights, and louse densities for all surviving BTD were assessed using Spearman's Rank Correlation analysis.

2.5.4 Grooming Bout Duration and Hair-loss Score

Arithmetic mean monthly grooming bout durations for all treatment groups were calculated and compared using ANOVA procedures; ANOVA procedures were also used to assess the effects of date on mean grooming bout duration. A test for correlation between times spent grooming and total louse density was performed using a Spearmen's Rank Correlation analysis; for this analysis, a significance level of $\alpha = 0.01$ was selected based on a small sample size.

To test for treatment effects on mean monthly hair-loss scores, mean hair-loss scores for all groups were compared using ANOVA procedures. To test for a correlation between mean monthly hair-loss scores and mean monthly grooming bout duration, Spearman's Rank Correlation analysis was used; a significance level of $\alpha = 0.01$ was selected based on a small sample size.

2.5.5 Black-tailed Deer Recovery

Correlations between mean monthly deer weights, hair loss scores, and louse abundances were tested using Spearman's Rank Correlation analysis. In addition, photographs of each deer through time were compared to determine any visual difference in hair coat and body condition.

3 RESULTS

3.1 Louse Identification

Summary of Key Results

- *No D. (Cervicola) sp. were identified on MD prior to experimental treatment.*
- *D. (Cervicola) sp. was the only louse species identified on BTD.*
- *D. (Cervicola) sp. was identified on six MD following treatment.*
- *Evidence of louse reproduction (eggs, and nymphs) was found on all MD deer infested with D. (Cervicola) sp..*
- *All D. (Cervicola) identified were female.*

A total of 40 louse samples from research deer (MD= 30, and BTD=10) were sent to NVSL for taxonomic identification. The only louse species identified on BTD was *D. (Cervicola)* (Table 5). No *D. (Cervicola) sp.* was identified on control MD during the study (Table 6). Native lice were identified on all but three MD prior to experimental treatment. Six had lice that were identified as *Damalinia (Tricholipeurus) lipeuroides*, five had lice identified as *Damalinia (Tricholipeurus)*

parallelus, and two had a combination of the two louse species. Three MD had no lice present prior to treatment. The exotic louse *D. (Cervicola) sp.* was identified on six MD following treatment; three from pen #4 (direct contact 1), two from pen #5 (direct contact 2) and one from pen #3 (inoculation). Native lice were identified on eight MD following treatment; the louse *D. (Tricholipeurus) odocoilei* was identified on one MD following treatment. Although *D. (Tricholipeurus) odocoilei* has been previously identified as *Damalinia (Tricholipeurus) parallelus*, evidence suggests that there are significant differences between the two native species (Jim Mertins, Personal communication).

Evidence of louse reproduction (eggs, and nymphs) was found on all MD infested with *D. (Cervicola)* sp. (Table 7), with the highest total number of eggs (n=14) and nymphs (n=65), from all samples, being observed on the same deer (G35A). More than one species of louse was identified on research deer P11 (Table 6); it is unknown whether or not the eggs and nymphs found on this deer were *D. (Cervicola) sp.*. All lice identified as *D. (Cervicola) sp.* were female.

Table 5. Identification of lice on black-tailed deer.

Animal Number	**Group (Pen#)**	**† Lice Species Identification**
G33	Direct Contact (5)	DC
G38	Direct Contact (5)	DC
G39	Direct Contact (5)	DC
G51	Direct Contact (5)	DC
G58	Direct Contact (5)	DC, DC*
P202	Direct Contact (4)	DC
P222	Direct Contact (4)	DC
P223	Direct Contact (4)	DC
P225	Direct Contact (4)	DC

† DC= *Damalinia (Cervicola) sp.*

*G58 *was surveyed twice with the same results.*

Table 6. Identification of lice for all surviving mule deer, pre and post treatment.

Animal Number	Treatment Group (Pen#)	† Lice Species Identification	
		Pre Treatment	Post Treatment
P216B	Direct Contact (4)	DTL	DC
P224	Direct Contact, (4)	DTL	DC
P221	Direct Contact, (4)	DTL	DC
G32	Direct Contact, (5)	DTL, DTP	DTL, DTP
G40	Direct Contact (5)	DTL	DTO, DT
R418	Direct Contact (5)	DTL	DC
G35A	Direct Contact (5)	NS	DC
P11	Inoculation (3)	DTP	DTL, DTP, DC
P12	Inoculation (3)	DTP	DTP
P13	Inoculation (3)	DTP, DT, DC	DTP
B411	Inoculation (3)	DTP	NS
B410	Inoculation (3)	DTP	DTP
O272	Control (2)	DTP	NS
O274	Control (2)	DTL	DTL
O282	Control (2)	NS	NS
O275	Control (2)	NS	DTO

†DTL = *DTL,* DTP=*Damalinia (Tricholipeurus) parallelus,* DT=*Damalinia (Tricholipeurus) sp.,* DC= *Damalinia (Cervicola)sp.,* DTO = *Damalinia (Tricholipeurus) odocoilei,* NS=No Sample Submitted (No lice found)

Table 7. Mean, standard deviation (SD), maximum (Max), minimum (Min), and total numbers of eggs and nymphs observed on research mule deer infested with *D. (Cervicola) sp*.

Research Deer	Pen No.	No. Eggs Observed					No. Nymphs Observed				
		Mean	SD	Max	Min	Total	Mean	SD	Max	Min	Total
P216	4	0.07	0.22	5	0	6	0.17	0.29	5	0	15
P224	4	0.03	0.09	2	0	3	0.23	0.36	5	0	20
P221	4	0.07	0.04	3	0	6	0.15	0.18	4	0	20
R418	5	0.11	0.35	5	0	8	0.21	0.18	2	0	4
G35A	5	0.18	0.41	5	0	14	1.45	1.28	35	0	65
P11	3	0.08	0.22	4	0	5	0.11	0.22	3	0	7

3.2 Louse Abundance

Summary of Key Results

3.2.1 Mule Deer

- *Direct contact MD had nearly 10 times the number of eggs and 3 times the number of nymphs than control MD.*
- *There was a significant difference in the abundance of lice observed on direct contact MD between pens 4 and 5.*
- *Males had more than twice as many lice on average than females.*
- *There was a significant effect of date on total louse abundance.*
- *Inoculation MD failed to develop persistent louse infestations.*

3.2.2 Black- tailed Deer

- *The total number of lice observed was significantly different between direct contact pens 4 and 5.*
- *There was a significant effect of date on total louse abundance.*
- *There was a rapid decline in mean adult and nymph lice after three months in the research facility.*

3.2.1 Mule Deer

A total of 1,504 louse counts were performed on research MD (n= 21) from April 2004 to May 2005, during which 1,643 lice were counted. Out of all louse

counts, including all louse species, adult lice were the most common ($\bar{x}$ = 4.87 ± 0.89) followed by nymphs ($\bar{x}$ = 3.50 ± 0.75) and eggs ($\bar{x}$ =.45 ± 0.17) (Table 8).

Table 8. Mean, range, and total abundances for different louse life stages from all mule deer louse counts.

Summary Statistics	***Eggs***	***Nymphs***	***Adults***
Mean	0.45	3.50	4.87
Standard Error	0.17	0.75	0.89
Range	24	73	65
Minimum	0	0	0
Maximum	24	73	65
Total No. Observed	85	651	907

Lice were most abundant on direct contact MD and control MD and least abundant on inoculation deer (Table 9). There was a significant difference ($F(1, 59) = 8.28$, $P<0.05$) in the abundance of lice observed on direct contact MD between pens 4 (n= 182) and 5 (n=626) (Figure 10).

Overall, there was no significant difference ($P>0.05$) in the abundance of adult lice found on control MD and direct contact MD; however the louse species identified was different between the two groups (See section 4.1). There were significant differences in the abundance of eggs ($F(1,132) = 5.72$, $P<0.05$) and nymphs ($F(1,132) = 3.99$, $P<0.05$) observed on control MD and direct contact MD, with direct contact MD having nearly 10 times the number of eggs and 3 times the number of nymphs.

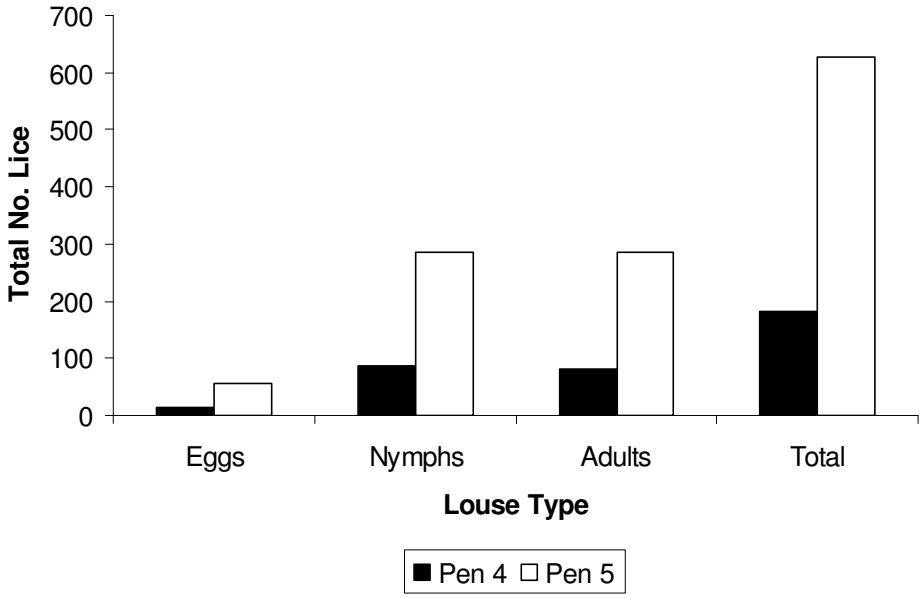

Figure 10. Difference in total numbers of eggs, nymphs and adults lice observed on mule deer in research pens 4 and 5.

There were unequal abundances of lice among individual deer in all treatment groups; some animals had more lice than others. This was partially due to the effect of gender ($T(184) = -2.09$, $P<0.05$), with males having more than twice as many lice on average than females (Table 10).

There was also a significant ($F(1,171) = 14.14$, $P<0.05$) effect of date on total louse abundance. Overall louse abundance rose to a maximum in May during both years followed by a subsequent decline in the summer (Figure 11). Louse numbers, once they declined in August 2004, did not increase until January 2005; within that time period there were no significant differences ($P>0.05$) in mean total louse abundance between or among groups. There were significant differences in the total number of nymphs ($F(1,26) = 14.68$, $P<0.05$) and adult lice ($F(1,26) = 15.10$, $P<0.05$) observed on the direct contact group and the control group following the second exposure to infested black-tailed deer, suggesting an effect of the direct contact treatment.

Despite inoculation in January 2005, inoculation MD failed to develop persistent louse infestations, and although inoculation MD had higher numbers of lice in July 2004, and from March to May 2005, than the control MD (Figure 11), the differences were not significant ($P>0.05$).

Table 9. Observed louse abundance by life stage. (The percentage of total represents the number observed for each group divided by the total number observed for all groups).

	Eggs		Nymphs		Adults		Total	
Treatment Group	**No. Observed**	**Percent of TOTAL**	**No. Observed**	**Percent of TOTAL**	**No. Observed**	**Percent of TOTAL**	**No. Observed**	**Percent of TOTAL**
Control	3	4%	163	25%	307	34%	473	29%
Inoculation	13	15%	115	17%	234	26%	362	22%
Direct Contact	69	81%	373	58%	366	40%	808	49%
TOTAL	85	100%	651	100%	907	100%	1643	100%

Table 10. Observed louse abundance by deer gender from all research groups. (The percentage of total represents the number observed for each group divided by the total number observed for all groups).

	Eggs		Nymphs		Adults		Total	
Gender	**No. Observed**	**Percent of TOTAL**	**No. Observed**	**Percent of TOTAL**	**No. Observed**	**Percent of TOTAL**	**No. Observed**	**Percent of TOTAL**
Female	23	27%	171	26%	292	32%	486	30%
Male	62	73%	480	74%	615	68%	1157	70%
TOTAL	85	100%	651	100%	907	100%	1643	100%

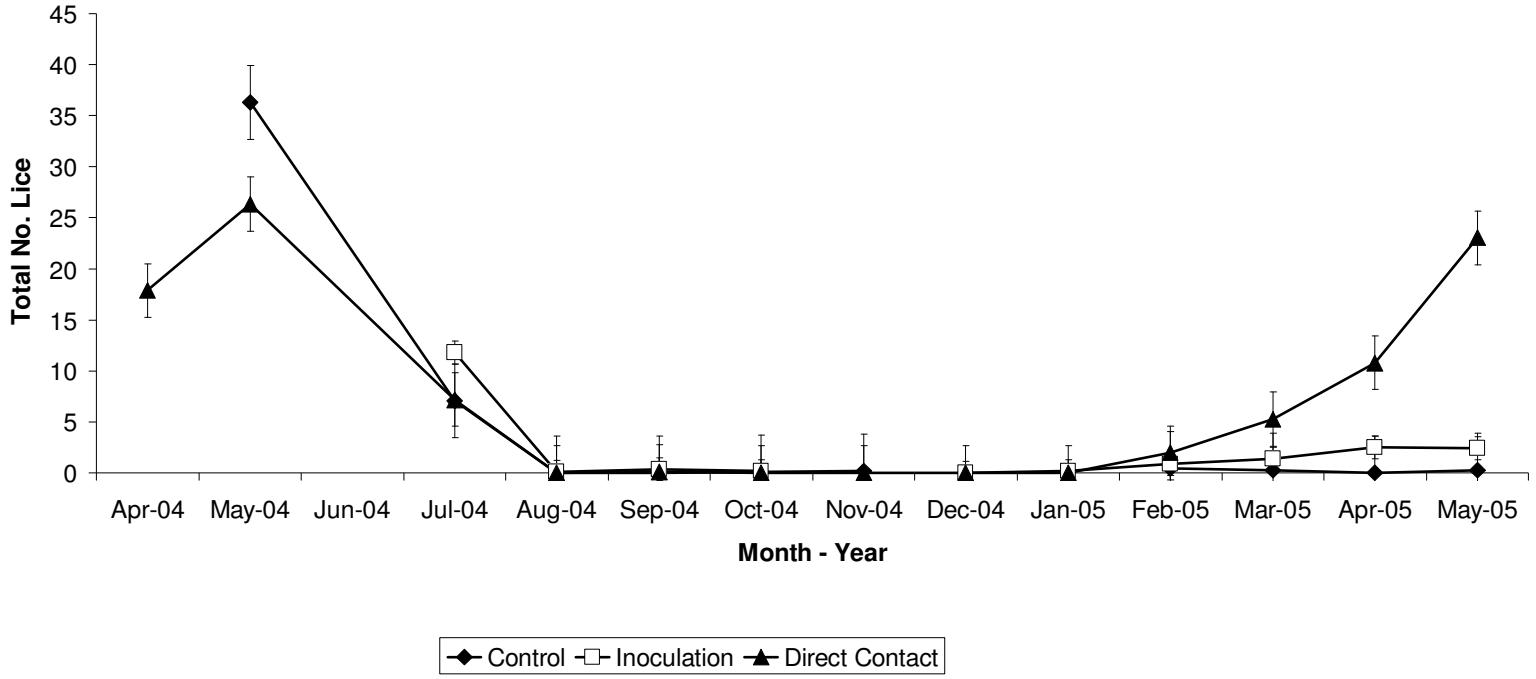

Figure 11. Mean total number of lice for all treatment groups from April 2004 through May 2005. For the direct contact group, pens nos. 4 and 5 were combined. Bars represent standard errors. Breaks indicate months when no data was collected.

3.2.2 Black-tailed Deer

A total of 1,024 louse counts were performed on research BTD (n= 16) deer from April 2004 to May 2005, during which 17,915 lice were counted. Eggs were the most common life history stage observed on average ($\bar{x}$ = 53 ± 11.6) followed by nymphs ($\bar{x}$ = 50 ± 11.5) and adults ($\bar{x}$ = 36 ± 6.2) (Table 11). The total number of lice observed on BTD was significantly different ($F_{(1,127)} = 9.22$, $P<0.05$) between direct contact pens, with BTD in pen 5 (n= 15,110) having higher total numbers of lice than BTD in pen 4 (n= 2,805) (Figure 12). This corresponded to the differences observed in direct contact MD in those same pens.

Table 11. Mean, range, and total abundances for different louse life history types from all black-tailed deer louse counts.

Summary Statistics	**Eggs**	**Nymphs**	**Adults**
Mean	53	50	36
Standard Error	11.6	11.5	6.2
Range	700	1087	325
Minimum	0	0	0
Maximum	700	1087	325
Total No. Observed	6841	6491	4583

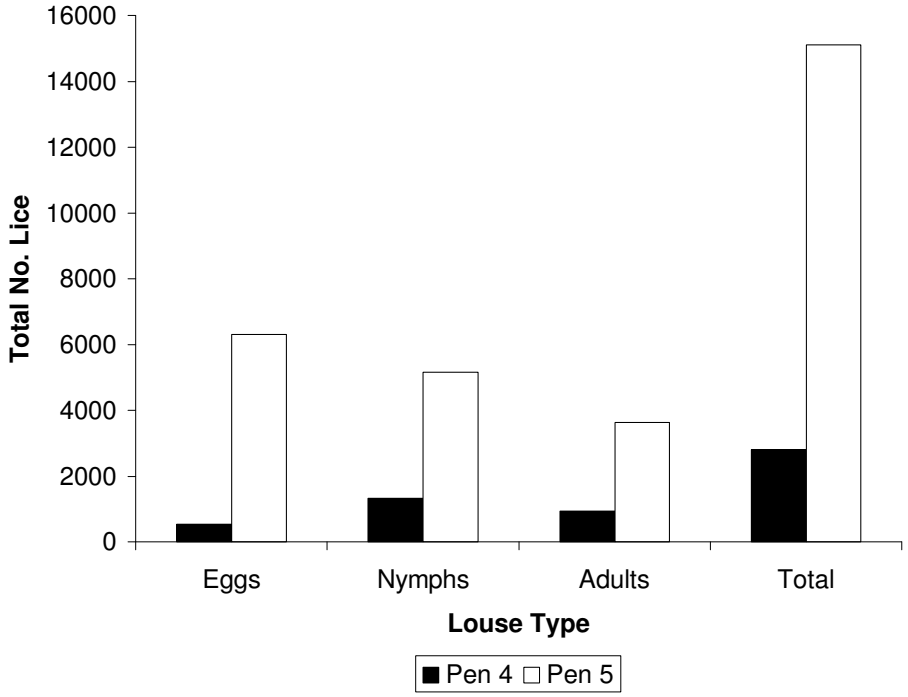

Figure 12. Differences in the total number of eggs, nymphs and adults lice observed on black-tailed deer in research pens 4 and 5.

Louse abundance on BTD peaked in May 2004, and decreased exponentially from May to August 2004. There were very few (n= 4) lice observed on BTD between September and December 2004 (Figure 13A). As a result, in December 2004, it was decided that a second group of affected BTD was needed to continue to provide some level of exposure to treatment MD in those groups. There was no significant difference ($P>0.05$) in the mean density of lice between the first ($\bar{x} = 556 \pm 102.9$) and second ($\bar{x} = 716 \pm 248.1$) group of BTD; and in both groups, the mean number of eggs and nymphs at any given time period were higher then the mean number of adults (Figure 13A and 13B). There was a difference in the peak louse period, with louse numbers in the first group peaking in May 2004 and the second group in February 2005. Despite this difference, both groups showed a rapid decline in mean adult and nymph lice after three months in the research facility.

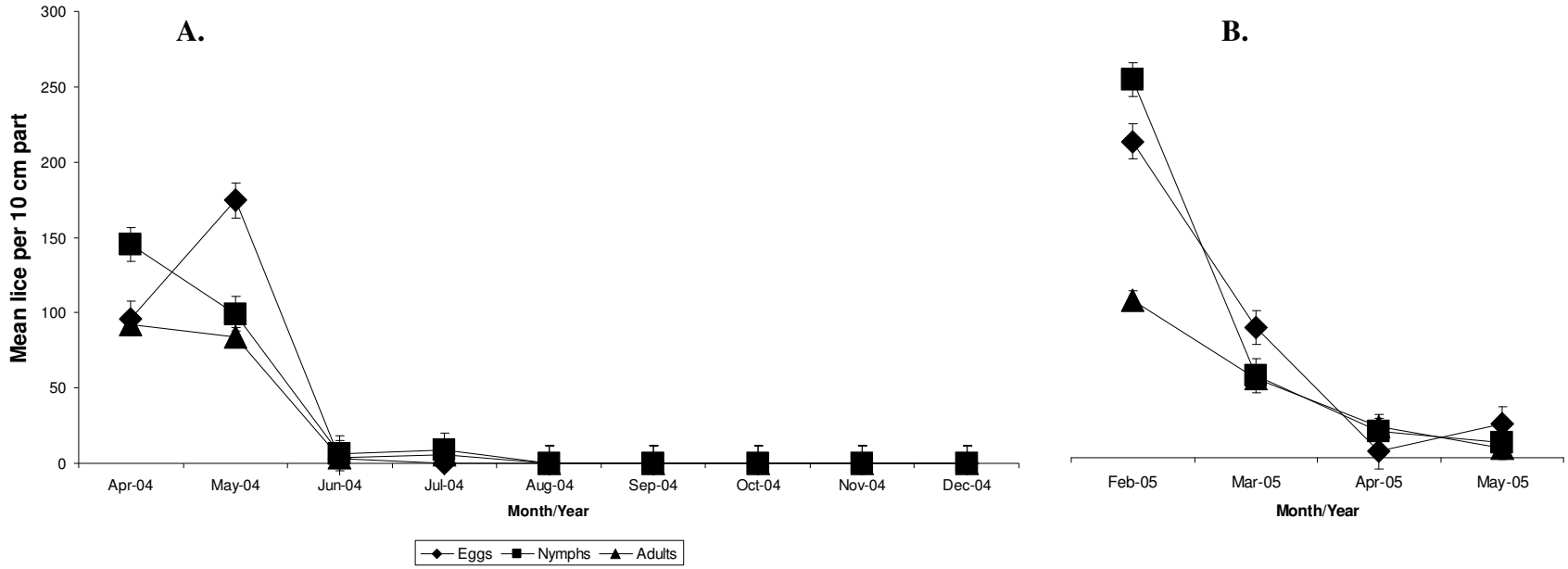

Figure 13. (A) Mean number of eggs, nymphs, and adult lice per 10cm hair part for direct contact black-tailed deer (treatment group 1) from April 2004 – December 2004 and (B) from treatment group 2 February 2005 to May 2005. Bars represent standard errors.

3.3 Spatial Distribution of Lice on Deer Infested with *Damalinia (Cervicola) sp.*

Summary of Key Results

3.3.1 Mule Deer

- *Lice were generally most abundant on the back and groin of infested MD.*
- *There were substantial differences in the representation of different louse life stages on different body regions of MD.*
- *In each body region, all louse types showed distinct seasonality in their abundance with higher numbers occurring during the late winter and early spring, and lower numbers occurring during the late spring and early summer.*

3.3.2 Black- tailed Deer

- *Lice were generally most abundant on the head and rump of infested BTD.*
- *There were substantial differences in the representation of different louse life stages on different body regions of BTD.*
- *In each body region, all louse types showed distinct seasonality in their abundance with higher numbers occurring during the late winter and early spring, and lower numbers occurring during the late spring and early summer.*

3.3.1 Mule Deer

Overall, lice were most abundant on the back (n=546) and groin (n=544) of infested MD (Figure 14). This was particularly evident during the first three months of the study from April to June 2004, and the last four months of the study February to May 2005 (Figure 15). This was also the period when the highest overall louse abundance was observed (Figure 11).

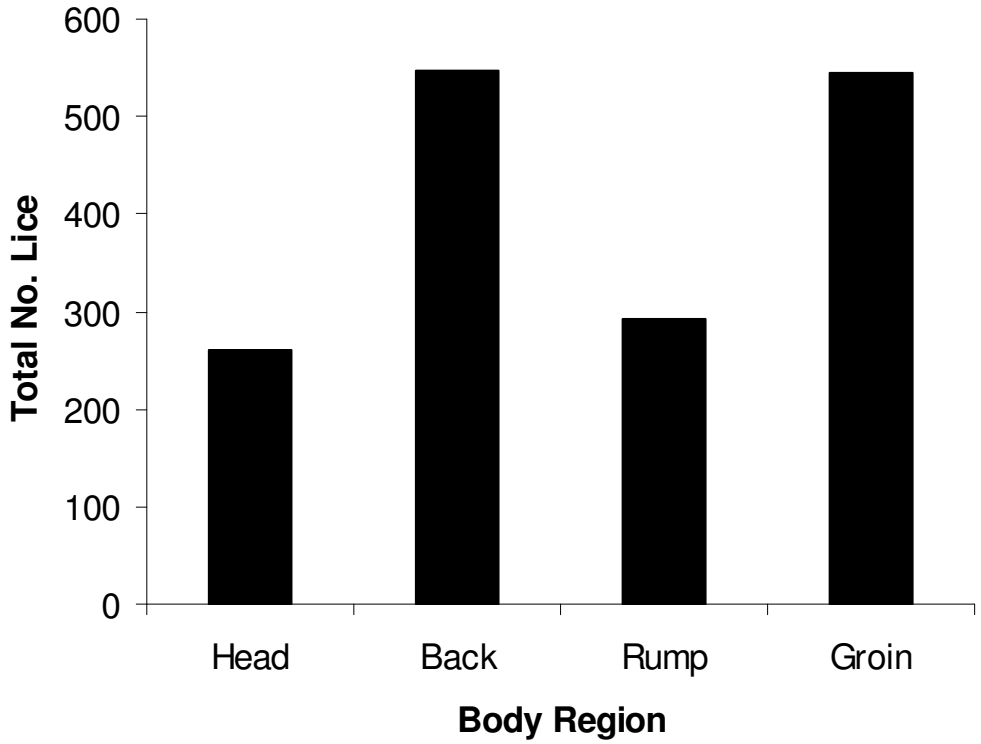

Figure 14. Differences between the total numbers of lice found on four body regions (head, back, rump, and groin) of mule deer.

There were differences in the representation of different louse life stages on different body regions of MD (Figure 15). All louse types were documented on each of the four body regions sampled; however, there were overall differences in the percentage of abundance (total number of eggs, nymphs, and adults sampled in a given region divided by the sum of all lice sampled in that region) observed in each body region. Adult lice were most abundant on the head (52.1%) and rump (47.7%). Nymphs were most abundant on the back (58.9%) and groin (53.7%), and eggs were most abundant on the head and neck (30.9%).

In each body region, all louse types showed distinct seasonality in their abundance (Figure 16), with higher number occurring during the late winter and early spring, and lower numbers occurring during the late spring and early summer. Between April 2004 and July 2004, nymphs were most abundant on the back, groin,

and head; eggs were most abundant on the head and rump; and adults were most abundant on the back, groin and rump. From July 2004 to January 2005 there were very few lice found in any of the body regions. From February 2005 to May 2005, nymphs were most abundant on the head and rump; eggs were most abundant the rump; and adults were most abundant on the groin and head.

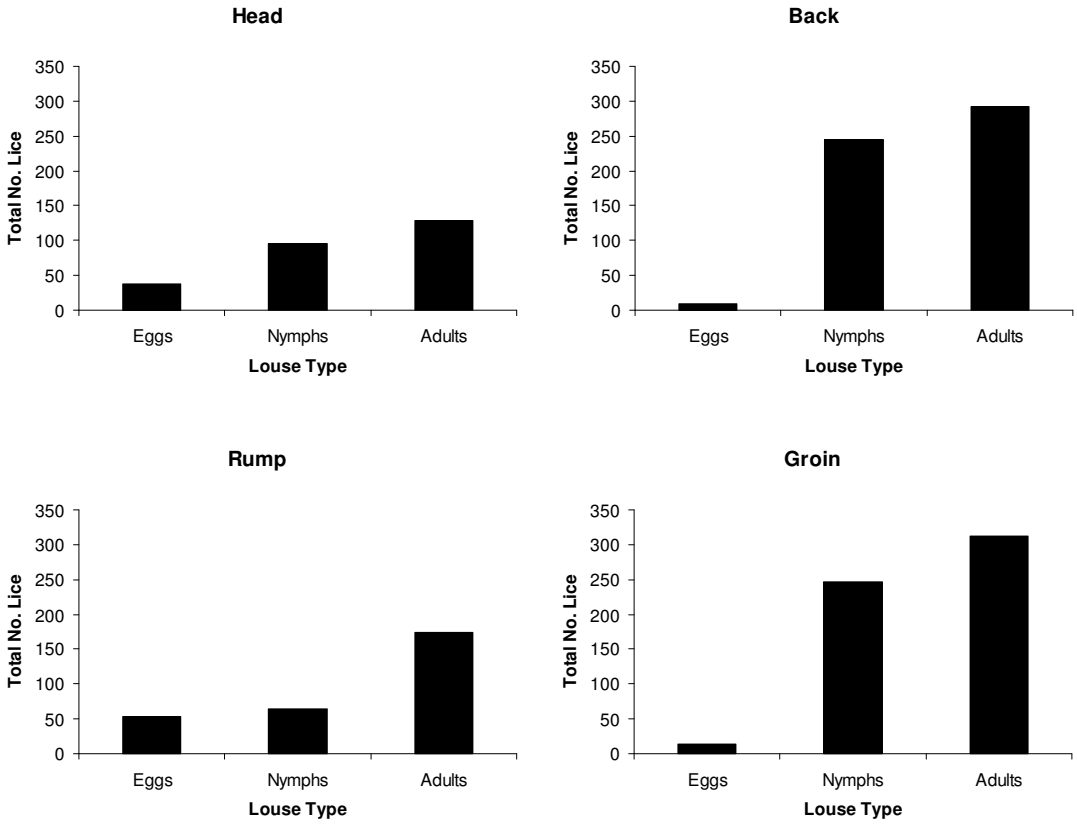

Figure 15. Total numbers of eggs, nymphs and adult lice observed on the head, back, rump, and groin of mule deer.

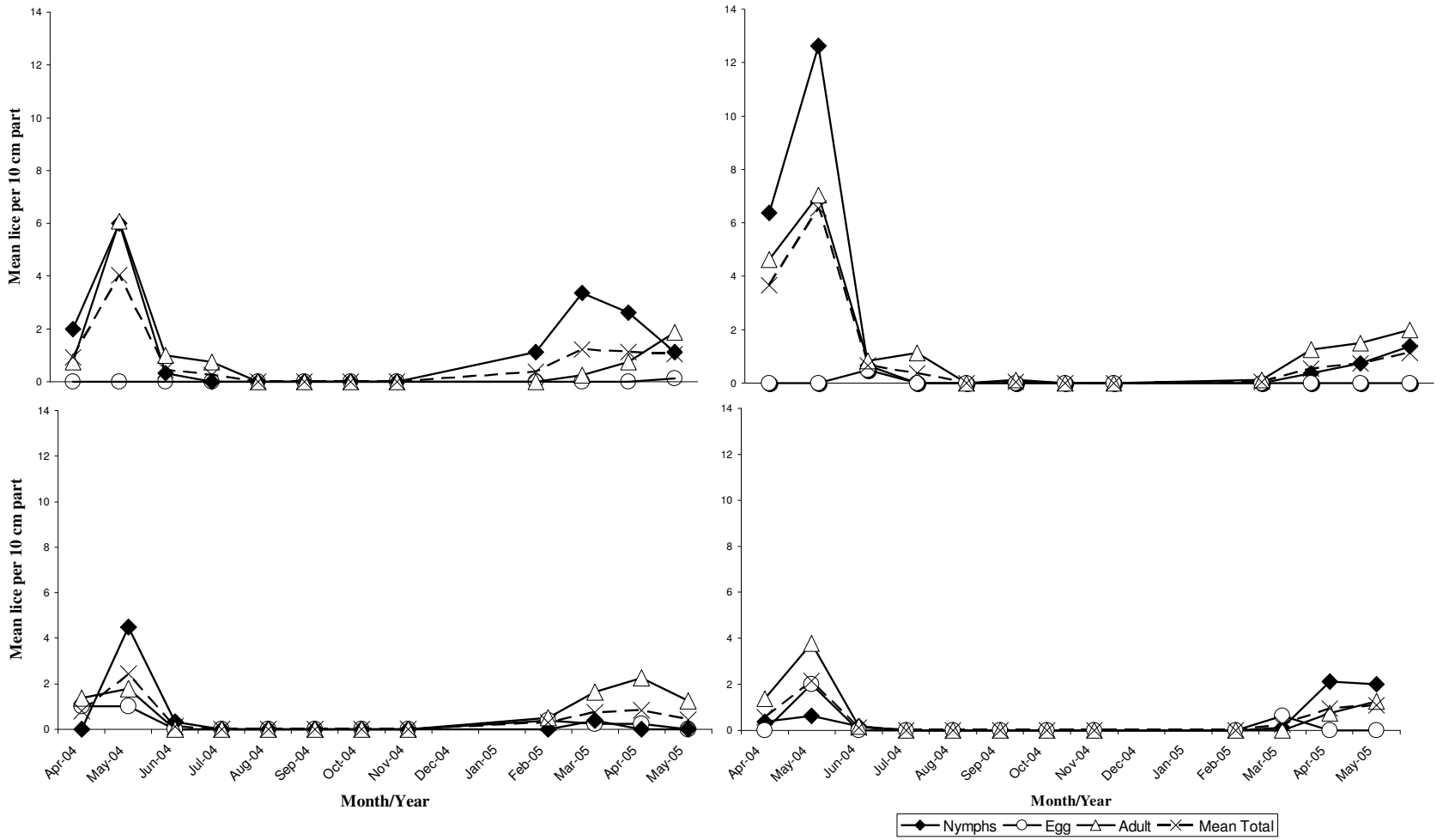

Figure 16. Mean numbers of eggs, nymphal, and adult lice per 10cm hair part on the back (*upper left*), groin (*upper right*), head (*lower left*), and rump *(lower right)* of mule deer infested with *Damalinia (Cervicola) sp.* from April 2004 to May 2005.

3.3.2 Black-tailed Deer

Overall, lice were generally most abundant on the head (n= 5,365) and rump (n=4,797) of infested BTD (Figure 17). This was particularly so during the first three months of the study from April 2004 to June 2004, and the last four months of the study from February 2005 to May 2005. These were also the time periods of the highest overall louse abundance in BTD (Figure 13A and B).

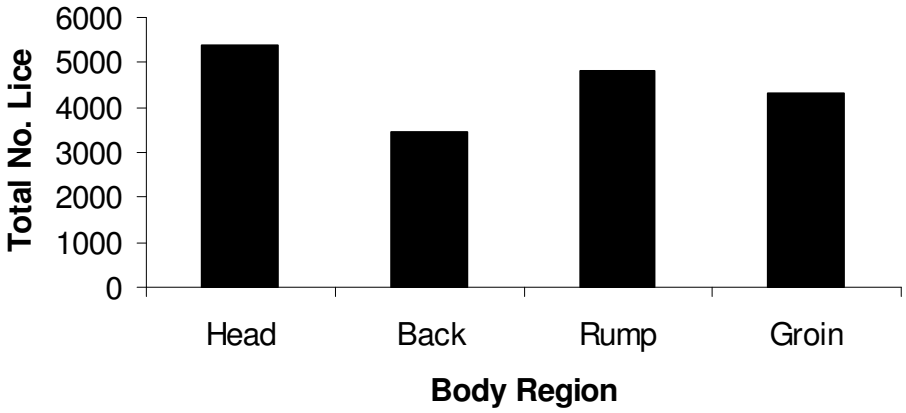

Figure 17. Differences between the total numbers of lice found on four body regions (head, back, rump, and groin) of black-tailed deer.

There were substantial differences in the representation of different life history stages on different body regions of BTD (Figure 18). All louse types were documented on each of the four body regions sampled; however, there were overall differences in the percentage of abundance (total number of eggs, nymphs, and adults sampled in a given region divided by the sum of all lice (types) sampled in that region) observed in each body region. Adults were most abundant on the groin (35.1%) and head (27.7%), nymphs were most abundant on the back (56.3%) and rump (47.6%), and eggs were most abundant on the head (57.3%).

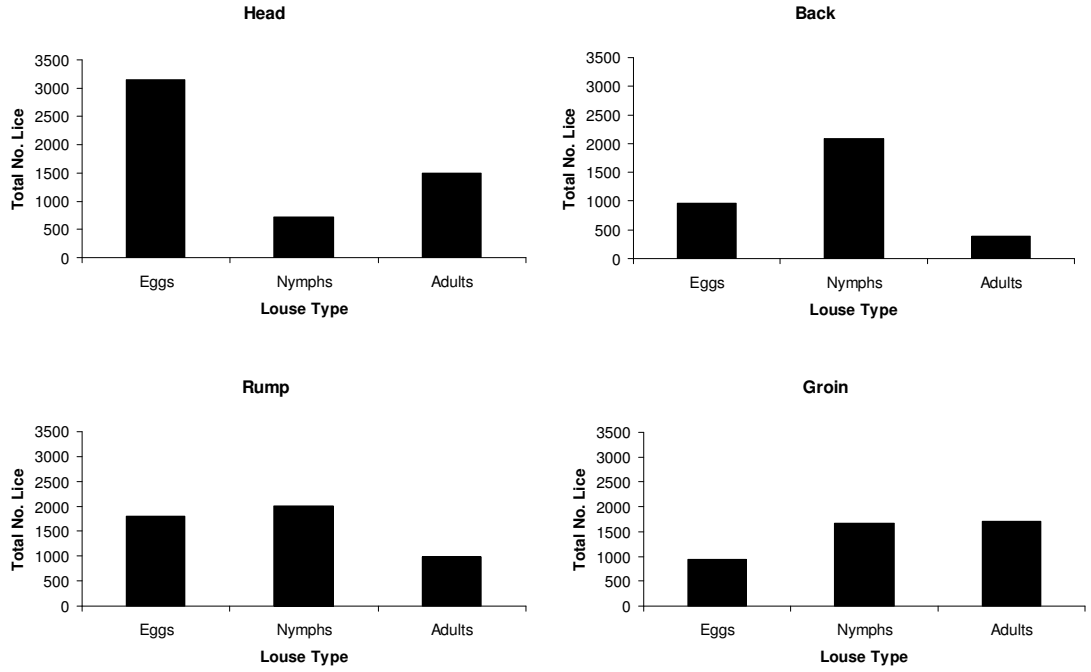

Figure 18. Total numbers of eggs, nymphs and adult lice observed on the head, back, rump, and groin of black-tailed deer.

All louse types showed distinct seasonality in their abundance (Figure 19), with higher numbers occurring during the late winter and early spring, and lower numbers occurring during the late spring and early summer. Between April 2004 and July 2004, nymphs were most abundant on the back, and groin, eggs were most abundant on the head and rump, and adults were most abundant on the groin and rump. From July 2004 to December 2004 there were very few lice observed on any of the body regions, and from January 2005 to May 2005, nymphs were most abundant on the back and groin, eggs were most abundant on the back, groin, and head, and adults were most abundant on the groin and head.

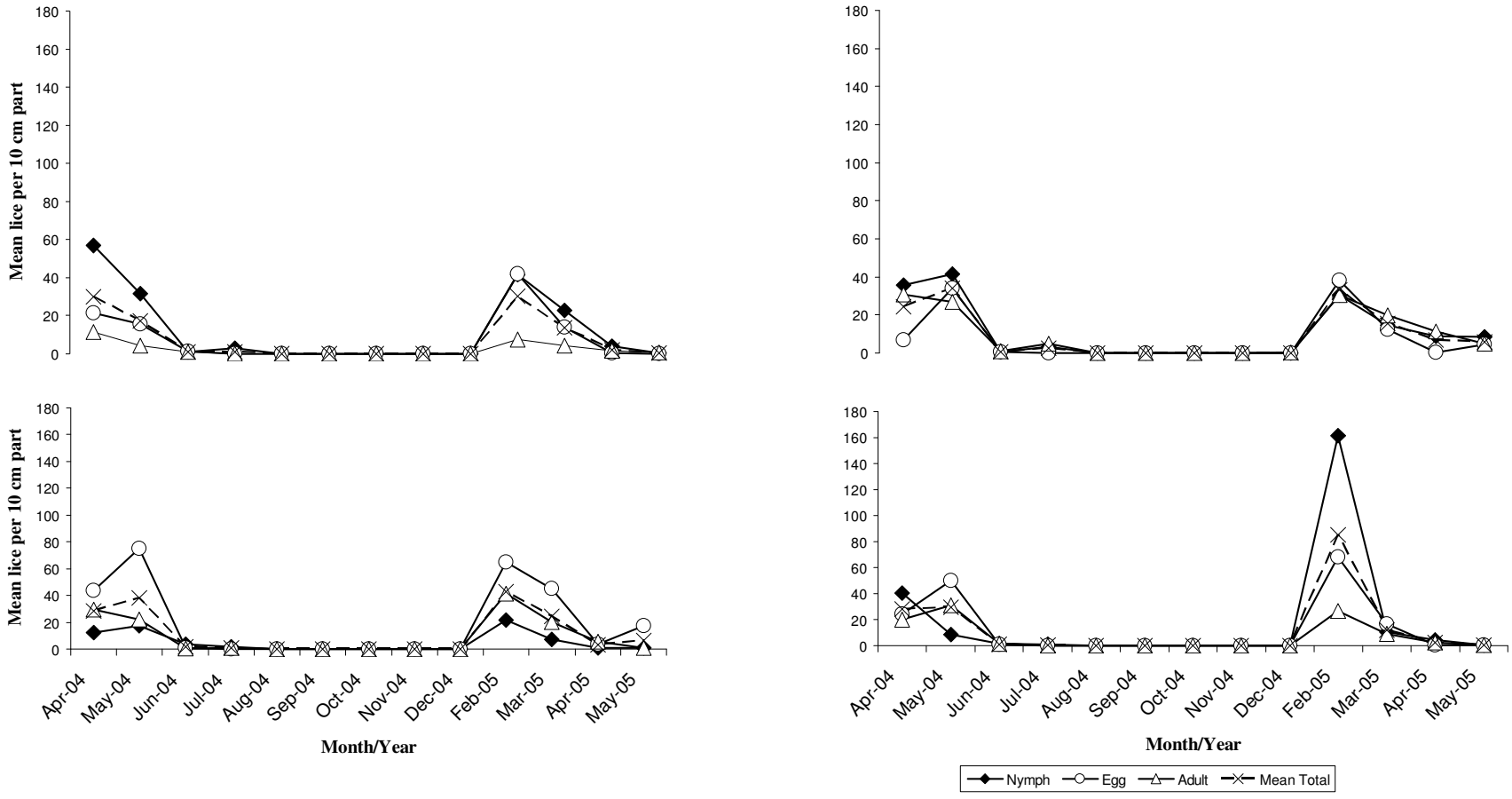

Figure 19. Mean number of eggs, nymph, and adult lice per 10cm hair part on the back (*upper left*), groin (*upper right*), head (*lower left*), and rump (lower right) of black-tailed deer infested with *Damalinia (Cervicola) sp.* from April 2004 to May 2005.

3.4 Changes in Deer Weight

Summary of Key Results

3.4.1 Mule Deer Weights

- *The highest mean weight was observed in the control group.*
- *The lowest mean weight was observed in the direct contact group.*
- *Despite high quality nutrition, the mean weight decreased in all treatment groups between December 2004 and January 2005.*
- *Between January and April 2005, control MD weighed 7-9kgs more on average than direct contact MD or inoculation MD.*

3.4.2 Black- tailed Deer Weights

- *Mean weights in BTD increased by approximately 17 kg on average from April 2004 to November.*
- *There were slight decreases in mean weight between November and December 2004.*
- *BTD in the first exposure group weighed 5 kgs more on average at capture, than those in the second exposure group.*

3.4.1 Mule Deer Weights

Weights for treatment mule deer were recorded 173 times from April 2004 to May 2005. There were noticeable differences in the overall mean weight, and the range of weights recorded (Table 12). The highest mean ($\bar{x} = 53 \pm 1.04$) and maximum (65.3 kg) weights were observed in the control group, the inoculation group had the lowest average weight (47.9 ± 0.81), and the lowest weight (18 kg, G35A), was observed in the direct contact group.

Table 12. Mean weights (kg) and range of weights recorded from all treatment mule deer from April 2004 to May 2005.

Summary Statistic	Control	Inoculation	Direct Contact
Mean	53.0	47.9	48.4
Standard Error	1.04	0.81	1.57
Range	36.0	29.7	46.4
Minimum	29.3	30.2	18.0
Maximum	65.3	59.9	64.4

There was no significant difference ($P>0.05$) in mean weights between groups from April 2004 to September 2004, but there was a significant difference ($F(2, 50) = 3.24$, $P<0.05$) between mean weights from October 2004 to February 2005 comparing the control group to both treatment groups (Figure 20). The control group weighed approximately 5-6 kg ($\bar{x} = 56.5 \pm 1.3$) more on average than direct contact MD ($\bar{x} = 51.4 \pm 4.0$) or inoculation MD ($\bar{x} = 50.8 \pm 2.0$). Despite high quality nutrition, the mean weight decreased in all treatment groups between December 2004 and January 2005 with control mule deer experiencing less of a decrease in weight than either the inoculation or direct contact groups. There was also a significant difference ($F(2, 71) = 9.73$, $P<.0.05$) in mean weights between groups from January 2005 to April 2005, with control MD weighing 7-9 kgs ($\bar{x} = 57.6 \pm 0.93$) more on average than direct contact MD ($\bar{x} = 50.1 \pm 2.4$) or inoculation MD ($\bar{x} = 48.5 \pm 0.97$).

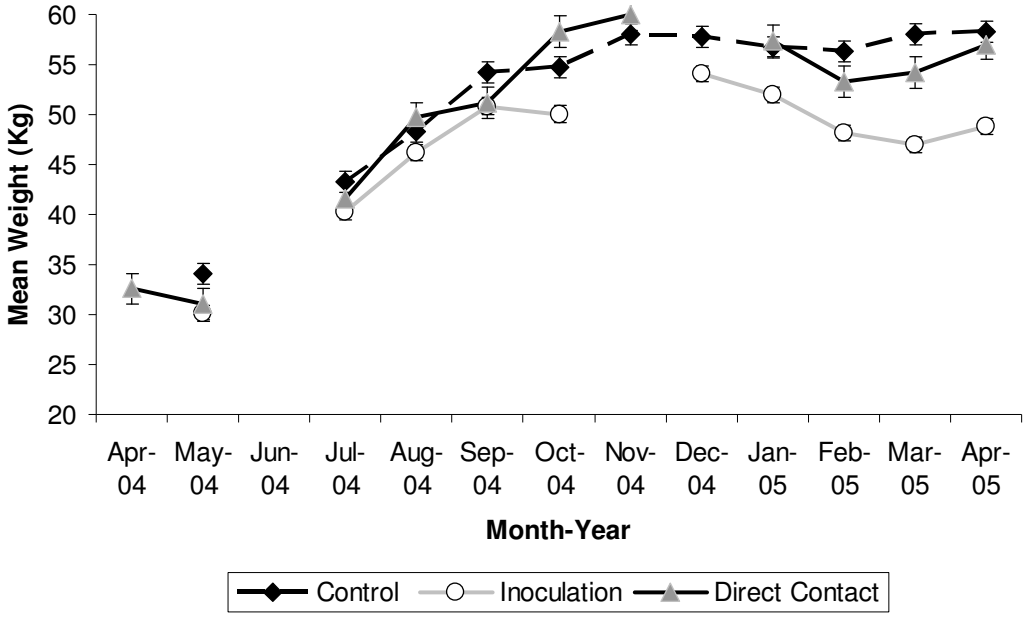

Figure 20. Mean weights of Control (n= 5), Inoculation (n=4), and Direct Contact (n=6) MD from April 2004 to May 2005. Bars indicate standard errors. (Breaks indicate months when no weight data was recorded).

3.4.2 Black-tailed Deer Weights

Weights for BTD were recorded 127 times from April 2004 to May 2005. There were no significant difference ($P>0.05$) in the mean weights observed between BTD in pens 4 and 5. Mean weights in BTD increased by approximately 17 kg on average from April 2004 ($\bar{x} = 26.4 \pm 1.1$)) to November 2004 ($\bar{x} = 43.9 \pm 2.0$) (Figure 21), with a slight (1 kg) decrease in mean weight between November and December ($\bar{x} = 42.9 \pm 1.8$) 2004.

Six new BTD were captured in January 2005. There was a significant difference between the mean starting weight of the first BTD (n=6) ($\bar{x} = 26.5 \pm 1.1$) group and the second BTD (n=6) ($\bar{x} = 21.8 \pm 1.6$) group, with BTD in the first group weighing approximately 5 kg more on average. This is most likely due to the fact that the second group of BTD were younger at the time of capture, than the first group. There was a 9 kg increase in mean weight in the second group from in February 2005 ($\bar{x} = 21.8 \pm 1.6$) to April 2005 ($\bar{x} = 29.0 \pm 2.0$). Mean weights from February 2005 to April 2005

for the first BTD group are addressed in section 4.6 (Black-tailed Deer Recovery) of this document.

There was a significant effect of gender on weight ($F(1, 86) = 6.20$, $P<0.05$) with male BTD weighing approximately 5 kg ($\bar{x} = 37.4 \pm 2.1$) more on average than females ($\bar{x} = 32.7 \pm 0.9$).

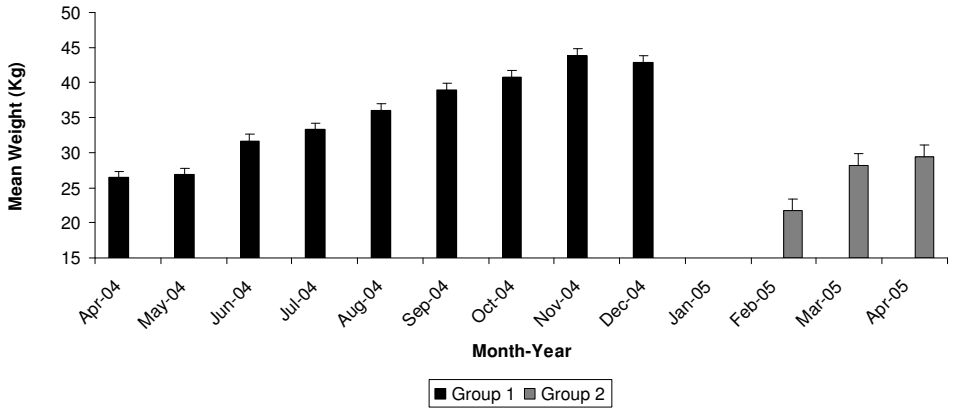

Figure 21. Change in mean weight for two groups of black-tailed deer from April 2004 to December 2004 (group 1) and from February 2005 to April 2005 (group 2). Bars represent standard errors.

3.5 Grooming Bout Duration

Summary of Key Results

- *Direct contact MD groomed more on average than the control or inoculation MD.*
- *There was a significant effect of date on time spent grooming.*
- *There was a positive relationship between time spent grooming and the density of lice in the direct contact MD.*

Overall, the average grooming bout duration for all groups was .75 minutes (SE = .12). The maximum grooming bout duration recorded was 5 minutes. There was a significant effect of treatment group on mean grooming bout duration in January ($F(2, 22) = 3.89$, $P<0.05$) and February ($F(2, 25) = 3.20$, $P<0.05$) with direct contact MD

grooming more on average than the control or inoculation groups (Figure 22) There were no significant (P>0.05) differences in the mean grooming bout duration among groups March to April 2005.

There was a significant effect of date (F (3, 95) = 4.6, P<0.05) on time spent grooming (Figure 22), with the highest mean grooming bout duration taking place in April 2005 for all groups. There was also a positive relationship between time spent grooming and the density of lice in the direct contact treatment group in January, February and April 2005 (Figure 23); neither the control or inoculation groups showed this relationship.

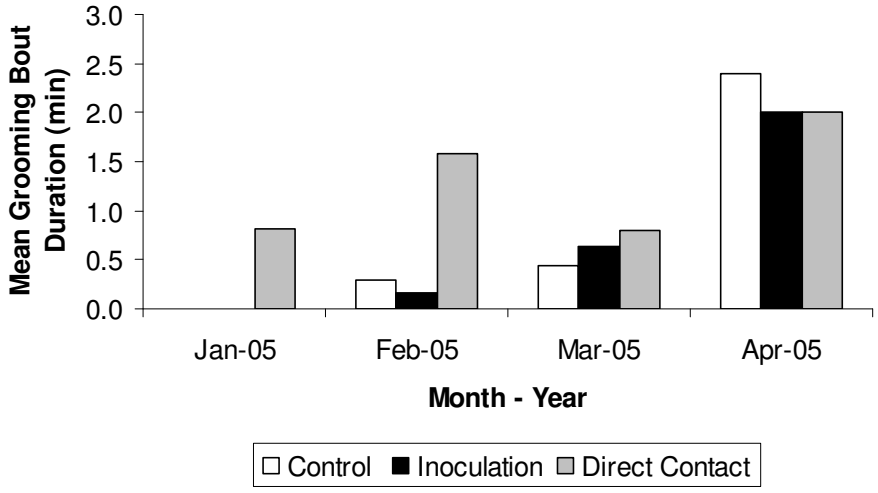

Figure 22. Mean grooming bout duration by month for mule deer in all pens from January through April 2005.

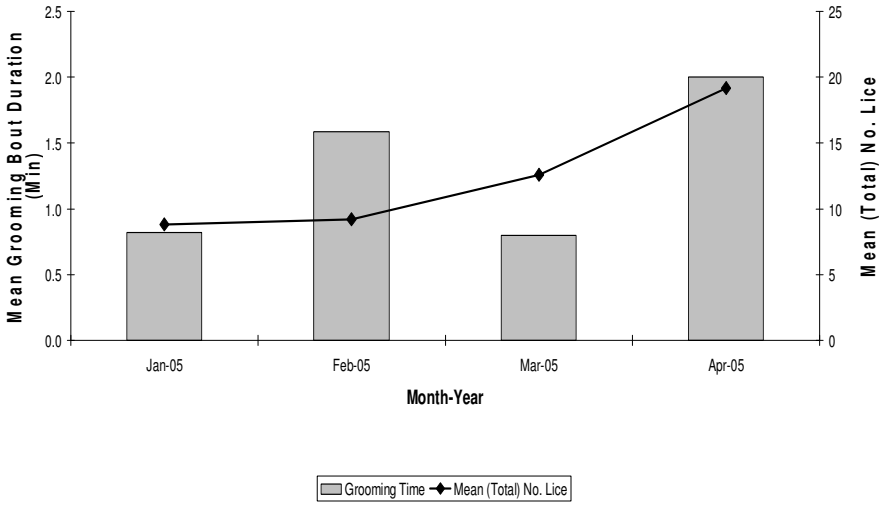

Figure 23. Mean (Total) numbers of lice versus mean grooming bout duration in direct contact mule deer from January 2005 to April 2005.

3.6 Hair-loss Score and Clinical Signs in Mule Deer

Summary of Key Results

- *Control MD never developed clinical signs of HLS.*
- *Direct contact MD had the highest mean hair-loss score of 0.9.*
- *Direct contact MD had the highest hair-loss score observed (Score = 4.0).*
- *Two direct contact MD developed hair-loss scores greater than 1.*
- *Hair-loss scores and mean grooming time for two direct contact MD were strongly correlated.*

At the onset of the study, all MD had hair-loss scores of zero, denoting no clinical signs of HLS. Overall, control MD never developed clinical signs of HLS (mean hair-loss score of 0); the inoculation group had a mean hair-loss score of 0.1 ± 0.04, and the direct contact group had the highest mean hair-loss score of 0.9 ± 0.15 (Table 13), in addition, the direct contact group had the highest hair-loss score observed (score = 4.0).

Table 13. Mean hair-loss scores and range of hair-loss scores observed in the control, inoculation, and direct contact treatment groups.

Summary Statistics	Control	Inoculation	Direct Contact
Mean	0.0	0.10	0.90
Standard Error	0.0	0.04	0.15
Range	0.0	1.0	4.0
Minimum	0.0	0.0	0.0
Maximum	0.0	1.0	4.0

Mean HLS score for inoculation MD peaked in January and February 2005 (Figure 24), following inoculation treatment. During this time period only light hair-loss was observed, and it was unclear whether this was an effect of the inoculation treatment.

Mean HLS in the direct contact MD varied over time (Figure 24) with a HLS score greater than 1 occurring in August 2004, November 2004, April 2005, and May 2005, with the highest peak (score > 2.0) occurring in May 2005.

Most deer in the direct contact treatment group did not develop persistent infestations of lice, nor did they develop clinical signs of hair-loss; however, two male MD (P224, and P221) exposed to infested BTD developed persistent louse infestations and clinical signs (Figure 25) with hair loss scores of 3 (P221) and 4 (P224) respectively. In addition hair-loss scores and mean grooming time for these two deer were strongly correlated ($r(6) = 0.88$, $P<0.01$) from January to April 2005 (Figure 26).

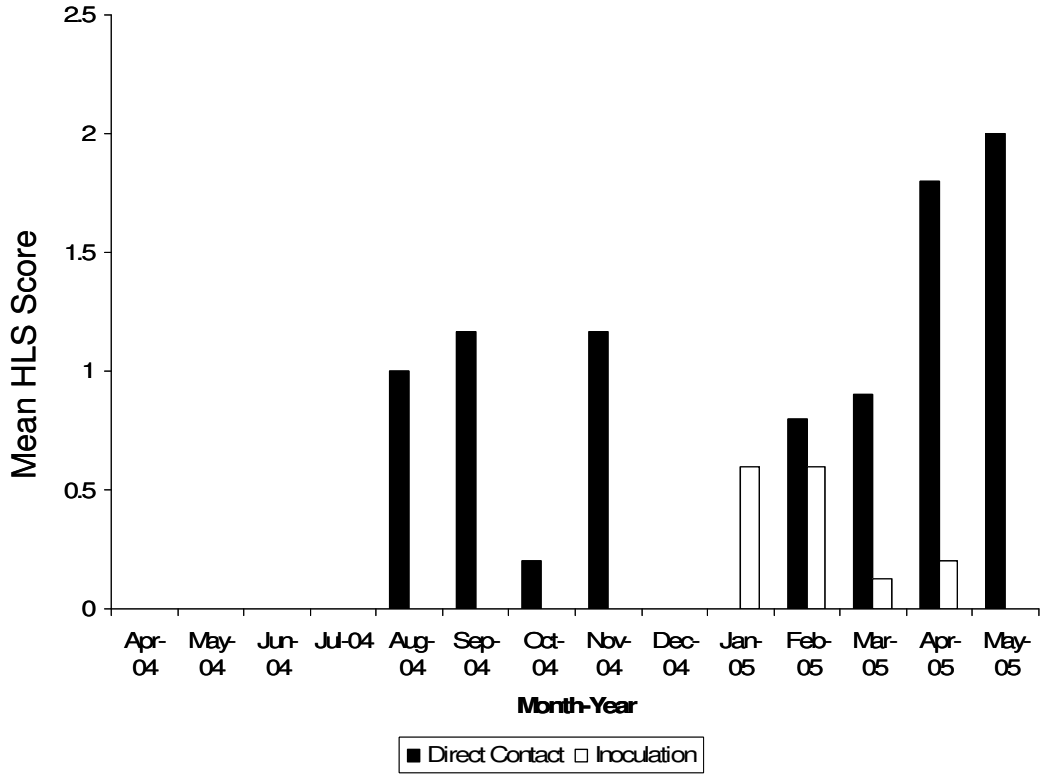

Figure 24. Mean hair-loss scores for direct contact and inoculation mule deer from April 2004 to May 2005. Gaps represent period where no data was collected, or when no visible signs of hair-loss were recorded.

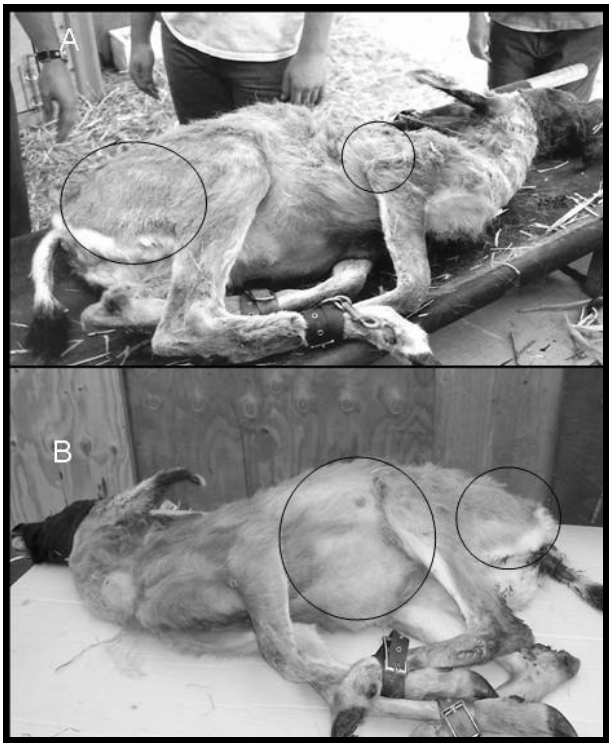

Figure 25. Two male mule deer showing clinical signs of hair-loss syndrome (A = P216; B = P224). Circles represent areas were hair has been groomed or removed.

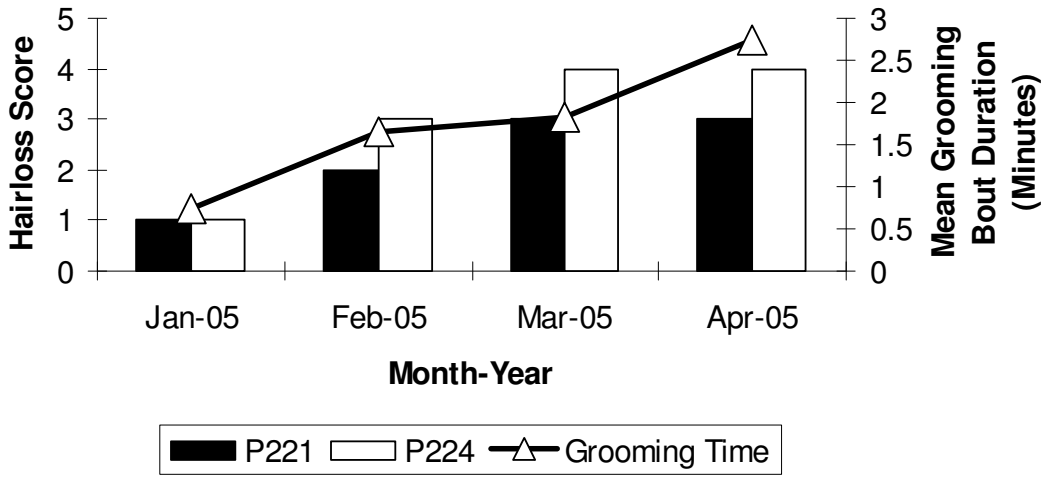

Figure 26. The relationship between hair-loss scores and mean grooming bout duration for direct contact mule deer P221 and P224 from January to April 2005.

3.7 Black-tailed Deer Recovery

Summary of Key Results

- *All BTD showed an increase in weight from April 2004 to April 2005.*
- *There was a significant inverse relationship between mean weight and the mean number of lice.*
- *There was a significant inverse correlation between mean weight and hair loss-score.*
- *There was a significant positive correlation between hair-loss score and total louse abundance.*

Eight BTD showed signs of recovery (increased weight, decreased hair-loss, and decreased louse numbers) within eight months of being placed in the research facility. Weights, hair loss scores, and total lice counts for all recovering BTD for April 2004, October 2004, and April 2005 are summarized in Table 14. All BTD showed an increase in weight from April 2004 to April 2005, with a minimum of 5.9 kg (G58), a max of 26.8 kg (G51), and an average of 14.6 kg (SE = 2.3). Three deer (G58, P202, and P223) lost > 1kg between October 2004, and April 2005; however all three had higher weight at the end of the study than at the beginning. There was a significant inverse relationships between mean weight and the mean number of lice ($r(24) = -0.68$, $P<.05$) for all BTD over the 14 month study period (Figure 27).

Mean hair-loss scores for BTD decreased dramatically from a high of 4 to a low of 0 by month nine of the study. There was a significant inverse correlation between mean weight and hair loss-score ($r(24) = -0.84$, $P<0.05$) for all deer (Figure 28) and a significant positive correlation ($r(24) = .51$, $P<0.05$) between hair-loss score and total lice (Figure 29). Mean (total) lice counts dropped substantially from May 2004 to June 2004, in conjunction with a slight reduction in hair-loss score. Figure 30 shows the transition in recovery for research deer G-51. At the end of the study none of the eight recovering deer had clinical signs of hair-loss syndrome.

Table 14. Weights, hair-loss score, and louse abundance for recovered black-tailed deer for April 2004, October 2004, and April 2005.

Deer ID	Apr-04			Oct-04			Apr-05		
	Weight (kg)	HLS Score	Total Lice	Weight (kg)	HLS Score (kg)	Total Lice	Weight (kg)	HLS Score	Total Lice
G 39	28.1	4	284	40.4	0	0	41.7	0	0
G 46	22.2	4	347	38.1	0	0	39.5	0	0
G 51	26.3	4	214	39.0	0	0	53.1	0	0
G 58	30.4	4	220	44.0	0	0	36.3	0	0
P 202	29.5	4	202	42.6	1	0	39.9	0	.5
P 222	29.0	4	292	40.4	1	0	39.9	0	.5
P 223	29.0	4	93	50.3	0	0	40.8	0	0
P 225	24.0	4	248	34.0	0	0	44.0	0	0

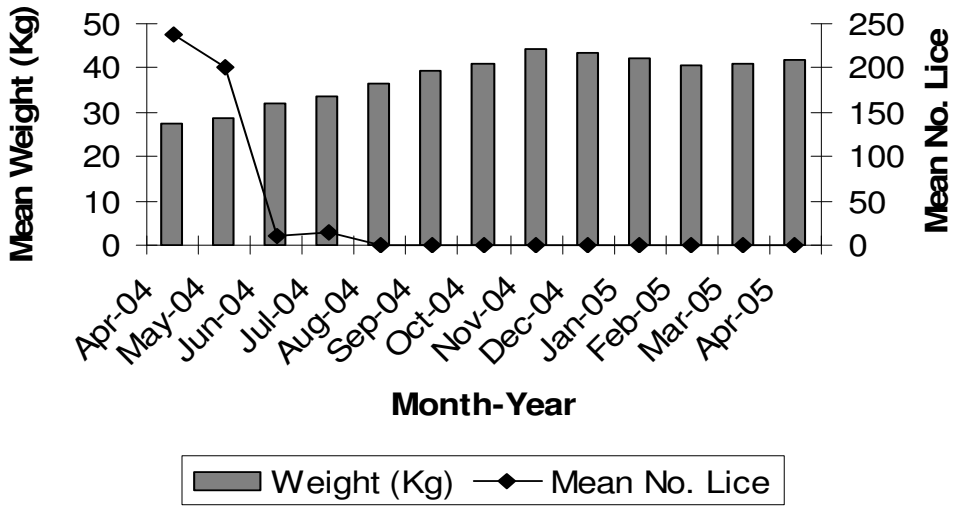

Figure 27. The relationship between mean weight and mean number of lice for all surviving black-tailed deer from April 2004-April 2005.

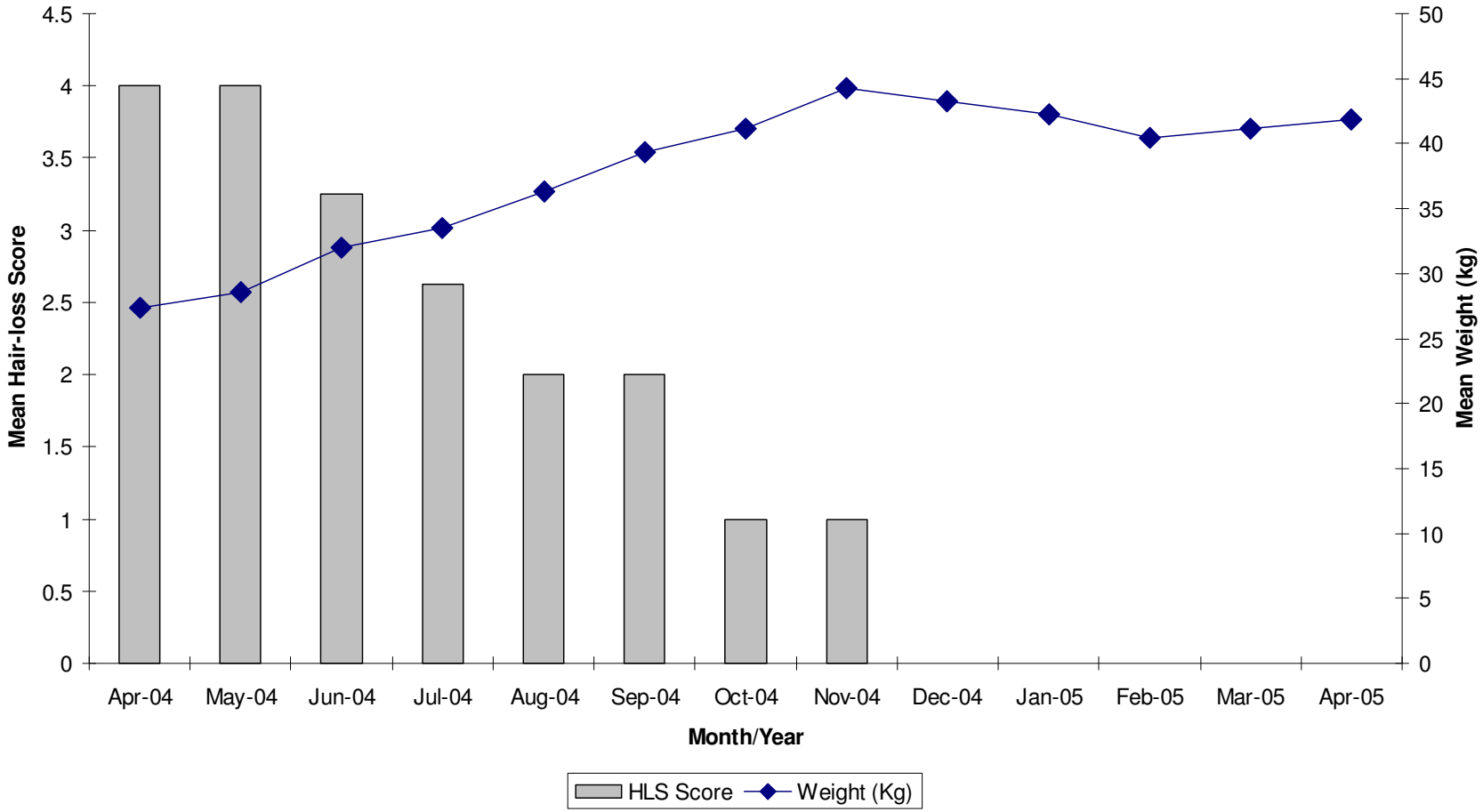

Figure 28. The relationship between mean weight and mean hair-loss score for all surviving black-tailed deer from April 2004 to April 2005. Gaps in the data represent times when no hair-loss was observed.

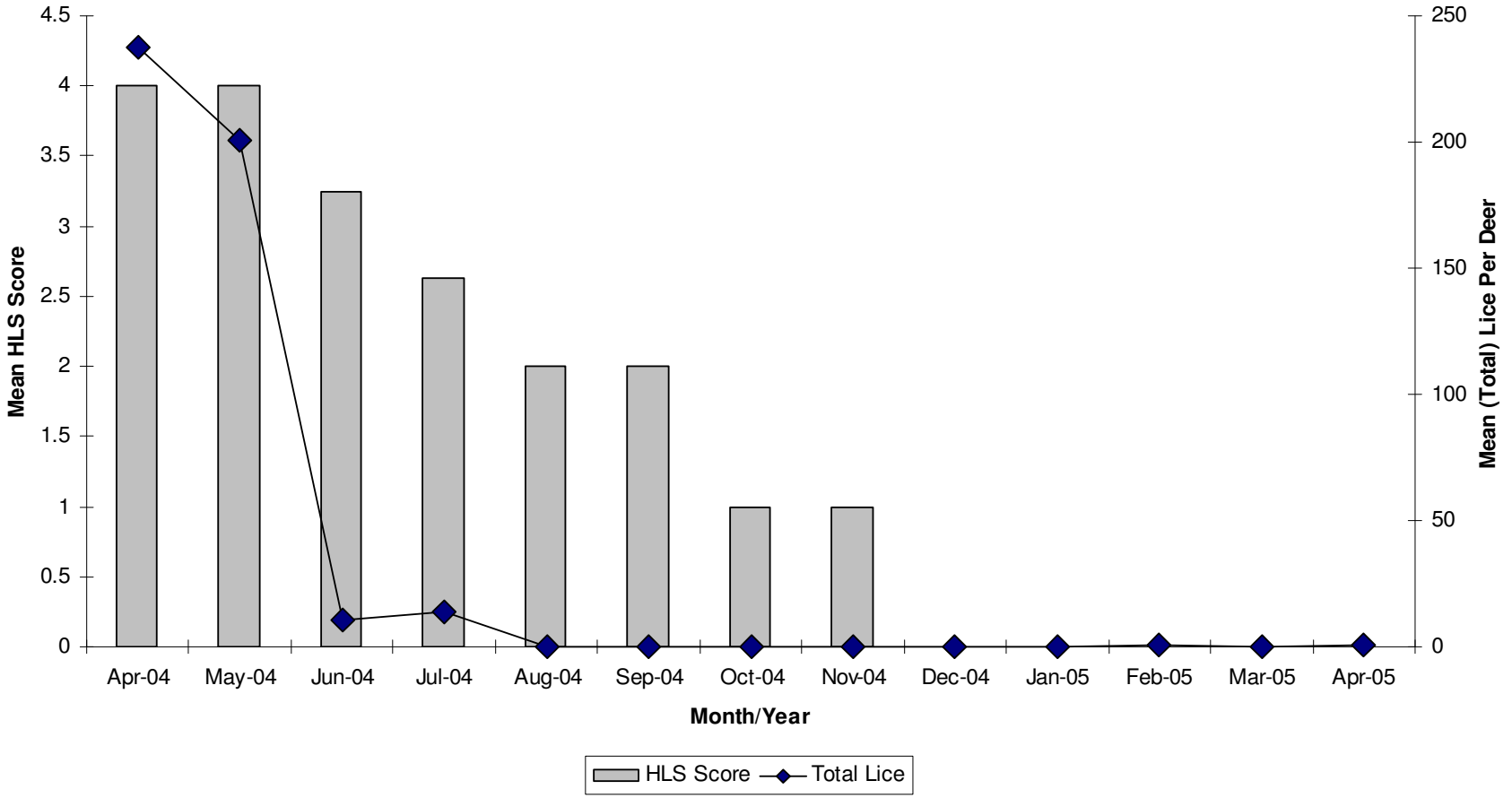

Figure 29. The relationship between mean (total) lice per deer and mean hair-loss score for all surviving black-tailed deer from April 2004-April 2005. Gaps in the data represent times when no hair-loss was observed.

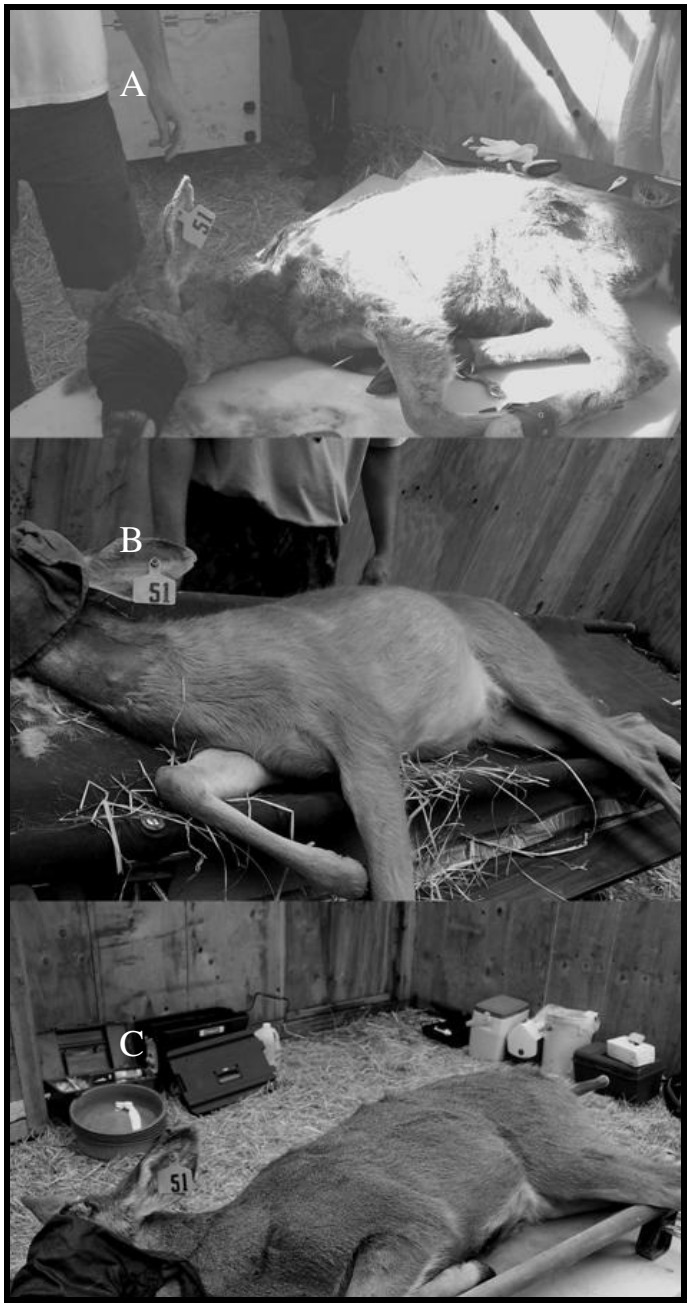

Figure 30. Recovery of research deer G-51 from April 2004 to April 2005. In April 2004 (A) this deer showed definite clinical signs of hair-loss and had very little hair left on its sides or rump. In October 2004, (B) this deer was beginning its winter molt; notice the darker winter hairs starting to push through the lighter summer guard hairs. In April 2005 (C) this deer had re-grown all of its hair and there were no signs of hair-loss remaining.

3.8 Mortality of Study Deer

Summary of Key Results

3.8.1 Mule Deer

- *Thirteen MD Mortalities occurred during the study.*
- *Nematode larvae (Dictyocaulus sp.) were present in the lungs of one male MD at death.*
- *Large numbers of lice (both native and nonnative) and/or some degree of hair-loss was observed in three MD at death.*
- *One MD had localized pediculosis caused by D. (Cervicola) sp. at death.*

3.8.2 Black- tailed Deer

- *Six BTD mortalities occurred during the study.*
- *Necropsied deer were severely emaciated upon examination and had signs of verminous pneumonia, and alopecia.*
- *Two genera of lungworm, Paraelaphostrongylus sp. and Dictyocaulus sp., were documented in necropsied deer.*

3.8.1 Mule Deer

A total of 13 MD mortalities occurred between March 2004 and May 2005. Four MD died prior to entering the study, and nine died during the study due to trauma unrelated to hair-loss syndrome. Nematode larvae (*Parelaphostrongylus sp.*) were present in the lungs of one male MD (B-408) at death and large numbers of lice (native and nonnative) and/or some degree of hair-loss was observed in 3 MD. Research MD B402, had a minor degree of hair-loss on the rump but no lice were found; research MD B409 had many lice (*D. Lipeuroides*) present at death in addition to isolated hair-loss; and research MD R-418, had localized pediculosis (Figure 31) caused by *D. (Cervicola) sp*. at death. In addition to lice, ticks (*Dermacentor albipictus)* and keds (*Lipoptena depressa, depressa*) were identified on MD during necropsies.

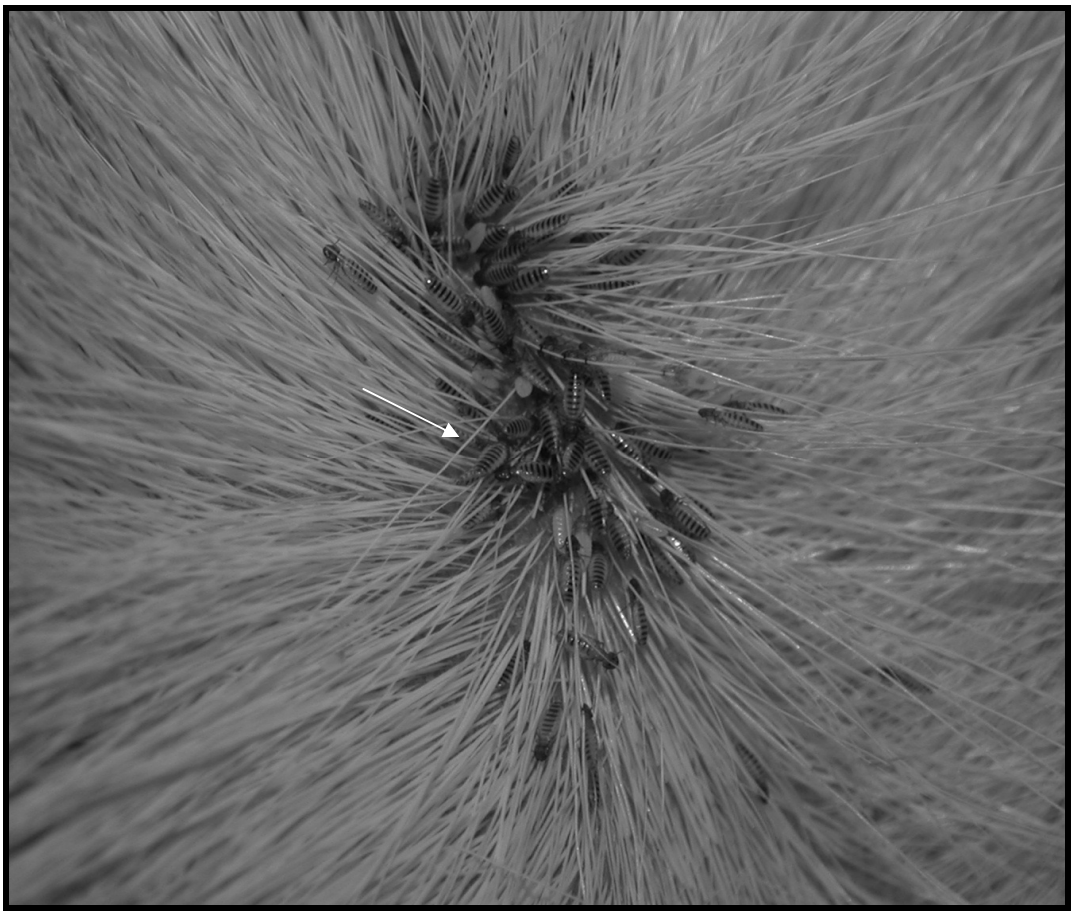

Figure 31. Localized pediculosis (*D. Cervicola sp*.) observed on research deer R-418 during necropsy. The white arrow is pointing at an adult (female) *D. (Cervicola) sp.*.

3.8.2 Black-tailed Deer

A total of six BTD mortalities (one male (G46A) and five females (G19, G33, G35, G38, P203)) occurred during the study. Three BTD died soon after capture, prior to entering the study, and three died during the study. A hair-loss score of 4 was documented for each deer prior to necropsy. All three deer that died during the study were severely emaciated upon examination and had signs of verminous pneumonia, and alopecia. Large numbers of lice (*D. (Cervicola) sp*.) were observed on G-33 and G-38 while low numbers were observed on P-203. Two genera of lungworm, *Paraelaphostrongylus sp*. and *Dictyocaulus sp*., were documented in all three BTD. In addition, adenoviral inclusion bodies were identified in the renal medullary epithelial

cells (confirmed by electron microscopy) of G-33, and *Demodex* organisms were observed in the follicles of the facial skin. BTD mortalities in this study were associated with similar secondary factors of HLS outlined by Bildfell et al. (2004).

4 DISCUSSION

The relationships between parasites and their hosts can be extremely complex. In most cases, hosts and parasites have evolved relationships that limit the harm caused by the association. On the other hand, parasites that are not endemic to an area can be very harmful to naive hosts. Westrom et al. (1976) documented the transmission of the invasive louse *Bovicola tibialis* from introduced fallow deer (*Dama dama*) to Columbian black-tailed deer in California. Although effects on BTD from the transfer of *Bovicola tibialis* were not discussed, the study showed that there was a high potential for transfer and establishment of non-native lice from introduced deer to native deer in cohabitated areas. More than 30 years later, a similar transfer of a non-native louse species (*D. (Cervicola) sp.*) has taken place, presumably due to contact between BTD deer and some unknown introduced deer species. Like *Bovicola tibialis*, this newly identified louse species has the ability to effectively reproduce on BTD, resulting in louse numbers which are larger than those historically observed in native louse infestations, Price et al. (2003) noted the effects of chewing lice on domestic and wild game when present in large numbers. The results of this study have shown that there is a direct link between *D. (Cervicola) sp.* and the development of hair-loss syndrome in BTD and MD.

4.1 Transmission of *Damalinia (Cervicola) Sp*. from Infested Black-tailed Deer to Rocky Mountain Mule Deer

This study has documented the first reported case of *D. (Cervicola) sp.* transmission from infested BTD to MD. It is unknown; however, whether this louse species can establish itself in populations of wild deer east of the Cascade Mountains (Cascades). The potential for transmission and the rate of transmission in the natural

environment may be dependant upon many factors. The effect of climatic variation on parasite development on the skin surface as well as the off–host environment, tied with the host's movement, and behavior patterns is likely to determine the potential for transmission to wild MD populations.

Unlike BTD, which occur throughout western Oregon in many habitats primarily at lower elevations, MD occur east of the Cascades, occupying habitats higher in elevation and harsher in climate (Verts and Caraway, 1998). The climate on the east side of the Cascades is much colder and drier than that on the west side. If environment is an important factor in louse transmission and persistence, differences in environmental conditions on the east side of the Cascades may in fact limit the potential spread and production of *D. (Cervicola) sp.*.

If host environment is the most important factor in louse transmission, one might presume that the greatest chance for MD exposure would be during the periods of habitat overlap in the summer months or during breeding in late fall. The results of our study have shown; however, that this time of year appears to support the lowest louse densities. Scott (1988) found that the total number of parasites in the environment is influenced by the number of infected hosts, as well as the environmental conditions (temperature, humidity) that determine the survival of the parasite. Although the summer months would most likely provide the best chance of exposure, the life history of the louse in addition to the variations in off-host environmental conditions, may limit the potential for effective transmission.

Although direct contact is the most plausible method of transmission between infested BTD and MD, other forms of transmission may exist during periods of high louse numbers. For example, there may be potential for introducing *D. (Cervicola) sp*. to wild MD populations through the movement and disposal of hunter harvested BTD carcasses or their parts. In addition there is a possibility of transmission from the clothing of hunters who have come in contact with infested BTD during the late fall and early winter. Crawford et al. (2001) found that *Bovicola bovis* nymphs could survive up to 29 days on unscoured wool; 16 days in shearing sheds; up to 10 days on

shearing equipment and clothing; and noted that these sources may be potential causes of new infestations. When *D. (Cervicola) sp.* is introduced either by natural spread or by another method of transmission, the effectiveness at which it transmits horizontally, exacerbated by behavioral ecology of MD, might provide for a high probability of becoming established in wild MD populations east of the Cascades.

4.2 The Role of *Damalinia (Cervicola) sp.* In the Development of Hair-loss Syndrome

From the information collected in this study, the clinical signs associated with HLS throughout the Pacific Northwest likely can be attributed to the result of irritation caused by the movements, feeding methods, or waste products of *D. (Cervicola) sp.*. During this study, *D. (Cervicola) sp.* was the only species of louse observed on surviving deer displaying clinical signs of hair-loss syndrome. In addition, through correlation analysis of hair loss score and grooming rates over time, and the timing of HLS development correlated with the seasonality of the exotic louse on captive BTD and MD. This study provides strong evidence that hair-loss syndrome is a direct result of *D. (Cervicola) sp.* infestations.

In its entirety, HLS may or may not be a multi-factorial disease. Although the loss of hair can be attributed to hypersensitivity brought on by pruritis, it is possible that environmental and physiological factors such as habitat quality, nutrition, and individual immunity may play an influential role in the epidemiology of this disease.

Overall body condition has the potential to affect many aspects of deer biology, individual immunity, and survival (ODFW, 2003). This study may have indirectly influenced factors which have been shown to affect body condition (diet, and endoparasites). By providing high quality forage and antihelminthic drugs, it's possible that we influenced the overall condition of animals in this study. Bildfell et al. (2004), Foryet et al. (2004) and others have noted the association between heavy infestations of chewing lice, endoparasite infestation, and poor nutrition.

In this study, louse numbers on captive deer provided with high quality forage and antihelminthic drugs did not increase as much in the winter as they likely would have in the absence of drugs and high quality feed. These results suggest that a high quality diet, in conjunction with reductions in internal parasites, may influence a deer's ability to reduce louse burdens.

The exact reason louse numbers failed to increase during this study cannot be determined, because experimental variations in daily nutrition and endoparasite infestations were controlled in all captive deer. We can speculate; however, that increased condition brought on by a high quality diet was probably the most influential factor in suppression of louse numbers.

During this study endoparasite numbers were not examined on a routine basis; necropsy results from mortalities were used to determine the effectiveness of treatment. We found that despite treatment with antihelminthics on three week intervals, some BTD had elevated levels of endoparasites at death. Given this information, it is hard to determine whether or not changes in louse abundances and changes in animal condition relied upon antihelminthic treatments. Regardless, it is possible that antihelminthic treatments reduced endoparasite burdens just enough to limit their effects on body condition.

Supplementing research deer diets with high quality forage was most likely responsible for the mean increase in weight for all deer from April 2004-April 2005. Despite the mean overall increase during that time period, the mean weight of research deer decreased during the winter; a consistent pattern reflected in nature (Seal et al., 1972).

The quality and availability of forage prior to winter is probably the most important factor contributing to the body condition of deer, thus it is reasonable to assume that deer utilizing areas with low quality forage prior to winter will be in poorer condition and therefore more susceptible to *D. (Cervicola) sp.* infestations. Nelson (2004) noted that immune function is compromised by the chronic stressors of

winter, which include starvation and malnutrition, leaving animals more susceptible to disease.

How is it that these lice persist from year to year in the population when we seem to see them drop off in numbers until they are essentially absent from the host? *D. (Cervicola) sp.* is most likely perpetuated in a population of deer through a seasonal fluctuation in numbers on carrier animals (animals susceptible to infestation). An animal under stress will usually support a larger parasite population than normal, and deer that are young or in poor condition have a tendency to carry heavier lice infestations (Scott, 1988). According to Price et al. (2003) most louse species tend to follow a strict binomial distribution, in which some hosts have very few lice while others tend to have larger numbers. A similar distribution was observed in our study.

The gender of the host may also influence the abundance of *D. (Cervicola) sp*.. We observed a significant effect of gender on louse numbers in BTD, with males having twice as many lice on average than females. Although the significance of this result, may be offset by the small sample size (n= 11; 6 females, 5 males) the finding is consistent with the gender bias observed in HLS cases by Bildfell et al. (2004).

Disproportioned effects of *D. (Cervicola) sp*. infestations associated with the sex of the host are not documented in the literature, but this phenomenon has been documented in other parasites. Main et al. (1981) documented higher number of ticks occurring on male white-tailed deer in Connecticut, and Prestwood et al. (1971) found higher levels of lungworms in male white-tailed deer of the Southeastern Untied States. Additionally, Zuk (1996B) noted that male deer often have higher parasite loads than females and added that immune function is better in females than in males of many vertebrate species.

The reasoning for this differential susceptibility is often attributed to the differences in sex steroid hormones (Bilbo and Nelson, 2001). Zuk, (1996A) suggested a direct relationship between the endocrine system, which controls the development of male ornaments, and the immune system. Bubenik (1989) suggested that a decrease in androgen levels may affect immuno-resistance in male deer therefore resulting in a

higher parasite levels than females; and Bilbo and Nelson (2001) noted the immunosuppressive effects of testosterone on B and T cell differentiation. Similar changes in sexual hormones may have influenced the susceptibility of wild BTD, in this study, to *D. (Cervicola) sp.* infestations prior to capture. Once these deer were castrated; however, the immune-compromising effects of the sexual hormones would have most likely been reduced. Additional research in this area is needed to determine the exact cause of gender bias in *D. (Cervicola) sp.* infestations, and in the potential development of HLS in wild deer.

The host's "climate" (external surface environment) may be another important influence on the potential for infestation as well as the degree of infestation. For example, skin temperature and moisture, quantity or thickness of hair (Reed et al., 2000B) the amount of oil on the skin, any olfactory signature that results from an animal's level of condition, and grooming behavior of the host may appreciably affect the size of the louse population.

This study has shown that the timing of the increasing phase of an infestation is crucial in the perpetuation of the louse life cycle. The results suggest that this occurs during the late fall and winter, when lice become reproductively active and experience a period of rapid population growth. This time period appears to follow the reproductive period of BTD, with louse numbers peaking just prior to parturition providing the lice their greatest opportunity for transmission (Johnson and Clayton, 2003).

Direct contact, however, is probably not the only mode of lice transmission. Price et al. (2003) found that exposure to bedding areas, and shared travel routes may also facilitate the spread of some chewing louse species. During this study many adult lice were found in the bedding of direct contact pens, suggesting a possibility of environmental transmission.

The sheep louse *Bovicola bovis,* have been shown to survive off their hosts for up to 24 days at temperatures ranging form 5-25ºC (Crawford et al., 2001). During an un-replicated off-host survival experiment in this study, adult and nymphal lice were

placed in Petri dishes at similar temperatures (5- 35ºC). We determined adult *D. Cervicola sp.* could survive up to seven days off the host.

At some population level, most likely determined by the size, condition, and immunity of the host, the antigens created by the lice begin to elicit an acute allergic reaction inducing pruritic grooming behaviors. The grooming behaviors (licking, chewing, rubbing and shaking) observed in this study, which peaked during the late spring and early summer, resulted in the removal of pelage (self-mutilation). This peak in grooming was observed during the time of highest louse numbers and about the beginning of the summer molt.

Once on a new host, the spatial distribution of *D. Cervicola sp.* likely leads to the pattern of hair-loss observed on infested deer. In this study, lice were typically observed throughout the all body regions observed in research deer; however, there appeared to be seasonal hotspots where eggs, nymphs, and adults were commonly found. The reason for these hotspots was not directly clear; however, one might speculate that the head, back and rump were preferred based on the limited effectiveness of host grooming behavior to reduce louse populations in those areas.

It is possible that host defense grooming in addition to changing pelage and environmental factors, were responsible for the spatial distribution of lice during the spring, and in fact the reduction in louse populations observed in this study during the summer months was strongly correlated with grooming behavior. Price et al. (2003) demonstrated that removal of pelage in conjunction with seasonal molting of pelage may help to reduce parasite numbers in the summer months, and added that the most important defenses against lice are oral grooming and scratching. In addition, Price et al. (2003) and Johnson and Clayton, (2003) found that louse numbers are profoundly affected by variation in temperature and humidity near the host's skin. Based on these findings, it is possible that pruritic grooming and summer molting reduce louse abundance by changing hair coat density, increasing exposure to solar radiation, and increasing skin temperatures.

Although many of the black-tailed deer in this study showed signs of hair-loss syndrome in the first summer of the study, there were few lice found on them after the summer molt. It was not clear from this study, or from the literature, where lice go during the hot summer months. We observed a few nymph and adult lice in the hairs of the back during June, July, and August, but found no lice in that same area in September. If solar radiation was a key limiting factor for louse survival as suggested by James (1999), we would have expected observe increasing louse densities in the regions of the host most unlikely to be affected by direct sunlight, such as the groin. Instead, we observed greater numbers of lice on the head and back where sunlight would presumably have the greatest affect.

The source of their proliferation during the onset of winter was also unclear. One potential explanation, although completely undocumented, is that the lice may have an off-host resistant or dormant stage which allows them to in live the environment during the summer months. If there is a dormant stage, environmental cues prior to the winter may elicit a behavioral response to seek out hosts via heat detection or olfaction. Although nothing like this has been documented in chewing lice before, it is well within the realm of possibility when dealing with ectoparasites. One example, of this concept would be the winter tick (*Dermacentor albipictus*) who lays eggs in foliage in late spring, which hatch in late summer. Larvae then appear on the vegetation in the fall, approximately the same time as their host breeding season (Drew and Samuel, 1985).

It may also be possible that *D. (Cervicola) sp.* has evolved a life history strategy that utilizes the newly born offspring of their hosts as incubators during the summer months and that those offspring become carriers the following winter. This study has shown that louse abundance tends to peak just prior to the parturition period of black-tailed deer and fall shortly thereafter. In addition, new born fawns have distinctively different pelage than the adult summer pelage (Cowan and Raddi, 1971), which may provide better habitat for lice during the summer months.

Re-exposure to infested individuals may be important in perpetuating louse populations from one year to the next. In this study, once louse numbers dropped in the summer months, re-exposure to heavily infested individuals was needed to facilitate infestations the following winter in both BTD and MD, and the fawns may be the source for reinfestation. This study also demonstrated that continual contact with infested individuals was more efficient in transmitting lice than a one time inoculation.

Immune responses may play a significant role in the relationship between *D. (Cervicola) sp.* and wild deer populations. The timing and amount of hair loss can lead to the development of many secondary problems (Bildfell et al., 2004). For example, premature loss of winter hair coat in Canadian moose (*Alces alces*) populations due to winter tick (*Dermacentor albipictus*) infestations, correlated to an escalated heat loss and depletion of energy reserves (Mooring and Samuel, 1999) contributing to a large die-off (Pybus, 1999). In the wild, immunologically challenged deer, especially fawns with heavier louse infestations, and poorer body condition, have an increased risk of secondary effects that may ultimately lead to death. Fawns appear to be more susceptible to the syndrome then adult does and bucks, possibly due to excessive heat loss as a result of their larger surface area-to-body mass ratio (Mooring et al, 2004). Bender and Hall (2004) reported that HLS was prevalent in approximately 74% of fawns in western Washington although they could not link HLS prevalence to depressed fawn numbers.

Reactions to antigens from this invasive louse may diminish over time as the deer and lice acclimate to each other. In addition, if the strength of immune response is influenced genetically it is likely that the immune response in the population will diminish over time with the addition of offspring from surviving deer.

4.3 Management Implications

Hair-loss syndrome in BTD of Western Oregon and Washington is an important disease because of the potential to greatly reduce deer fitness. Demographic

data from BTD populations in western Oregon suggests that HLS may be significant factor in their decline (ODFW, unpublished data), primarily due to a loss in fawn recruitment. During the 2001 and 2002 survey seasons, both late winter fawn to doe and fawn - to- adult deer ratios dropped to the lowest levels ever recorded in the mid-coast region of Oregon (ODFW, 2003).

Wildlife managers are also concerned about the potential spread of HLS into MD populations, and the potential to reduce them. If HLS can manifest itself in MD east of the Cascades, we may see higher morbidity and mortality, particularly among juveniles, than we are currently observing in black-tailed deer populations. Unlike black-tailed deer which associate in maternal groups, on small home ranges throughout the year, MD tend to additionally gather in large herds and cover many miles in their seasonal migrations. Poor growing seasons and drought conditions east of the Cascades often leave MD food-stressed or in poor condition prior to entering winter. Deer in poor condition are more susceptible to heavy louse infestation, as observed in black-tailed deer captured for this study. Large louse burdens resulting in hair-loss would greatly increase a mule deer's susceptibility to the harsh winter conditions east of the Cascades, resulting in higher mortality rates. In addition to the increased morbidity and mortality, a rapid increase could be seen in the spread of lice throughout MD populations east of the Cascades due to the higher densities of MD when on winter ranges. As MD move away from their winter ranges in the spring, the potential for them to carry these lice to new areas would also be high.

In most biological invasions, the rate of spread is important in determining how quickly control measures should be instituted, and their intensity (Coblentz, 2000). Given that the louse species involved is an invasive species, it is possible that it will continue to expand its range until all suitable habitats are occupied. The habitat for this invasive species has two major variables: the host, and the climate where that host lives. Given that BTD are a subspecies of MD, and that this study identified *D. (Cervicola) sp*. on MD, it is likely that the climatic variable is the most important in limiting the spread of *D. (Cervicola) sp*..

If HLS is able to spread into wild MD populations, whether through direct contact or environmental exposure, the additive mortality as a result of its spread and the ensuing economic effects may be quite significant. Both Oregon and Washington rely heavily on hunter dollars to finance wildlife management, and based on data collected by the Oregon Department of Fish and Wildlife, MD hunting alone yielded $14.9-29.8 million in economic benefits in 2001 (ODFW, 2003).

Resource managers need to develop strategies to limit the potential for horizontal or environmental transmission from overlapping deer populations, or from movement of infested black-tailed deer pelts and carcasses across the Cascades. In addition, research is needed to determine the true relationship between HLS prevalence and declining population levels. Additionally further research to determine the genetic identity of the louse species involved, and the relationship between seeing the louse species and observing clinical signs, is needed.

4.4 Conclusions

In conclusion, it is now apparent that transmission of the exotic louse *D. (Cervicola) sp.* from infested BTD to non-infested MD is possible when the two species are held in direct contact. There is also an apparent link between the irritations caused by this infestation; grooming response; and loss of hair in both BTD and MD.

What is not apparent from this study, are the additional factors that may influence the susceptibility of the host animal to *D. (Cervicola) sp.* infestation (body condition, immunity, age nutrition, and gender), and the environmental factors (temperature, humidity, and solar radiation input) which may limit the survival and production of this invasive louse. Each of these aspects deserves further study.

There are also no clear explanations of where lice go during the summer months. Is there an off host life stage? Are lice populations perpetuated through carrier animals like newly born fawns? Some of these questions may be answered through genetic analysis of the louse species, while others may never be answered.

Resource managers should take the lessons learned from this disease, and use them to assess the potential for transmission of additional exotic parasites from many of the exotic species legally or illegally imported into the Pacific Northwest each year.

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APPENDIX

STUDY WEAKNESSES

Data Collection

Although every effort (training, oversight, and peer auditing) was made to assure accurate data collection, data in this study may have been influenced by inconsistencies and fluctuation in staffing. The data in this study was collected by multiple researchers over a 14 month period; not all individuals were present for each observation period. Furthermore; given that much of the data was observational (i.e. louse counts, hair-loss scores, and grooming bout duration), the quality of the results may have been influenced by each observers ability to adequately collect and record the information in a manner that was consistent with all other observers.

Study Environment

The study results may have also been influenced by the study location. Although mule deer were shown to be susceptible to hair-loss syndrome, this study was conducted on the west side of the Cascades; change in environment may have increased or decreased the susceptibility of mule deer. Additional stresses brought on by captivity may have also influenced louse abundances in both subspecies. Additionally, although every attempt was made to mimic natural conditions, this study used high quality nutrition, and anthelmenthic treatments to rule out confounding variables (diet and endoparasites) which may influence the potential for hair- loss development and transmission in the wild.

Timing of Exposure

The study results may have also been influenced by the timing of exposure. The timing of exposure to *D. (Cervicola) sp.*, whether through direct contact or

inoculation, did not take place until after the time period in which louse numbers were increasing which may have resulted in lower louse abundances, than if exposure had taken place earlier.

Deer Age

The age of the host animal may be an important factor in its susceptibility to lice infestations. Deer in this study were captured at 9 months of age and held in the study for until approximately 18 months of age. Had deer been captured earlier, the susceptibility to *D. (Cervicola)* sp. infestations may have been different. In addition since all mule deer were held over from one year to the next, they may have had a chance to develop some immunity to the louse thereby reducing their susceptibility in the second year.

Castration and Removal of Antlers on Male Research Deer

It is possible that castration of males prior to entering this study may have influenced the susceptibility of males to *D. (Cervicola) sp.* infestations. Bubenik (1989) suggested that hormonal status played an important role in the resistance of male deer to parasitic infestations. Additionally, during the removal of antlers, fly spray containing pyrethrins was used to reduce the potential for maggot infections on fresh wounds. These pyrethrins have the ability to kill and repel insects and may have influenced louse numbers.

Antihelminthic Treatments

Most antihelminthic drugs only target the adults and late stage larvae of endoparasites therefore a second treatment within two weeks of the first treatment is needed to eliminate developing larvae from those eggs. It is recognized that

lungworms are more difficult to eliminate, often requiring treatment on consecutive days for over a week so failure to completely eliminate these infections was not surprising. In addition the method, in which we treated research animals, may have lead to skewed dosages within each pen. By using a food supplement as opposed to an injection or topical application, some deer may have received higher treatment dose than others depending on their dominance status or condition. Housing these deer on pasture may have also permitted the opportunity for continuous re-infection.