Adult Cow and Calf Moose Survival in Maine

Final Report

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FINAL REPORT

EXECUTIVE SUMMARY

During a seven-year study on adult cow and calf survival in Maine (2014-2020), 417 calves (~8 months of age) and 128 adult cows were fitted with Global Positioning System (GPS) collars, ear tagged and sampled for winter ticks, blood parameters and internal parasites. The study was implemented in Wildlife Management Districts (WMD) 8 (2014-2020) and 2 (2016-2020) to investigate winter tick abundance on annual survival of adult cows and on over-winter survival of calves—adult survival was assessed up until the collar battery quit or the animal died (individuals were often monitored over multiple years). Field necropsies were conducted on moose that died within 12-48 hours of a mortality notification, excepting moose that were legally harvested, wounded, or illegally taken. We conducted limited necropsies on carcasses found in late stages of decomposition or those that had been heavily scavenged.

From May until the end of July, we conducted "walk-ins" or stalked near enough to directly observe all adult female moose to determine reproductive status and calf survival. Due to time constraints, mature cows (3+ years of age) were prioritized for observation over known yearling or 2-year-old cows less likely to calf.

Annual survival rates of adult cows were relatively high (90-92%) throughout the study except in 2014, when an abnormally high loss of adult cows (48%) was observed. Mean overwintering survival of calves in WMD 8 was 38% compared to 63% overwintering survival of calves in WMD 2. Winter tick abundance was higher on moose in WMD 8 and was associated with higher over-winter calf mortality and depressed reproduction; we recorded reduced ovulation rates and very low rates of twinning. Additional research is recommended to increase understanding of the relationships between moose densities and winter tick abundance considering expected climate change.

INTRODUCTION

Although Maine's moose population demonstrated a strong and prolonged period of population growth during the last few decades of the 20th century, in the early 2000's Department personnel began noticing an increase in the incidence of moose exhibiting winter hair loss and started encountering carcasses of calves in late winter with greater frequency. Concurrently, research in New Hampshire suggested higher loads of winter ticks infesting moose, with increased morbidity. Continued concern about the physical condition of Maine's moose became evident with public review and involvement in the Department's 2015-2025 Big Game Plan, resulting in a management objective of ensuring a “healthy” moose population. This investigation was undertaken to provide greater understanding of the relationships between winter tick and moose and impacts that winter tick are having on moose in the State. Adult female moose (cows) are an important reproductive segment of the population, and their relative physical condition influences the number and health of the calves they produce annually. To maintain or grow populations, calf survival rates must be sufficient to offset population losses.

STUDY AREAS

The project encompassed Maine’s WMDs 2 and 8 (Figure 1). Both units have extensive commercial forestlands within unincorporated townships (87% vs 96%). The land areas have multiple commercial and private landowners, but still heavily favor large scale commercial forestry. Both units are comprised of various age softwood, hardwood, and mixed stands (87% vs 80%), however mixed-wood stands are twice as prevalent within WMD 2. WMD 8 has 5% more scrub-shrub habitat and 3% more wetlands than WMD 2.

WMD 2 (initiated 2016) is in far northern Maine, extending over 1,160 square miles from Ashland west of State Highway 11 to the Allagash River and north from the Reality Road to the New Brunswick Border along the St. John River. WMD 8 (initiated 2014) is located along Maine’s western border, extending over 1,960 square miles from the west side of Moosehead Lake to the Quebec border and from the Golden Road south to Pleasant Ridge Plantation over to Flagstaff Lake and up State Highway 27 to the Canadian Border.

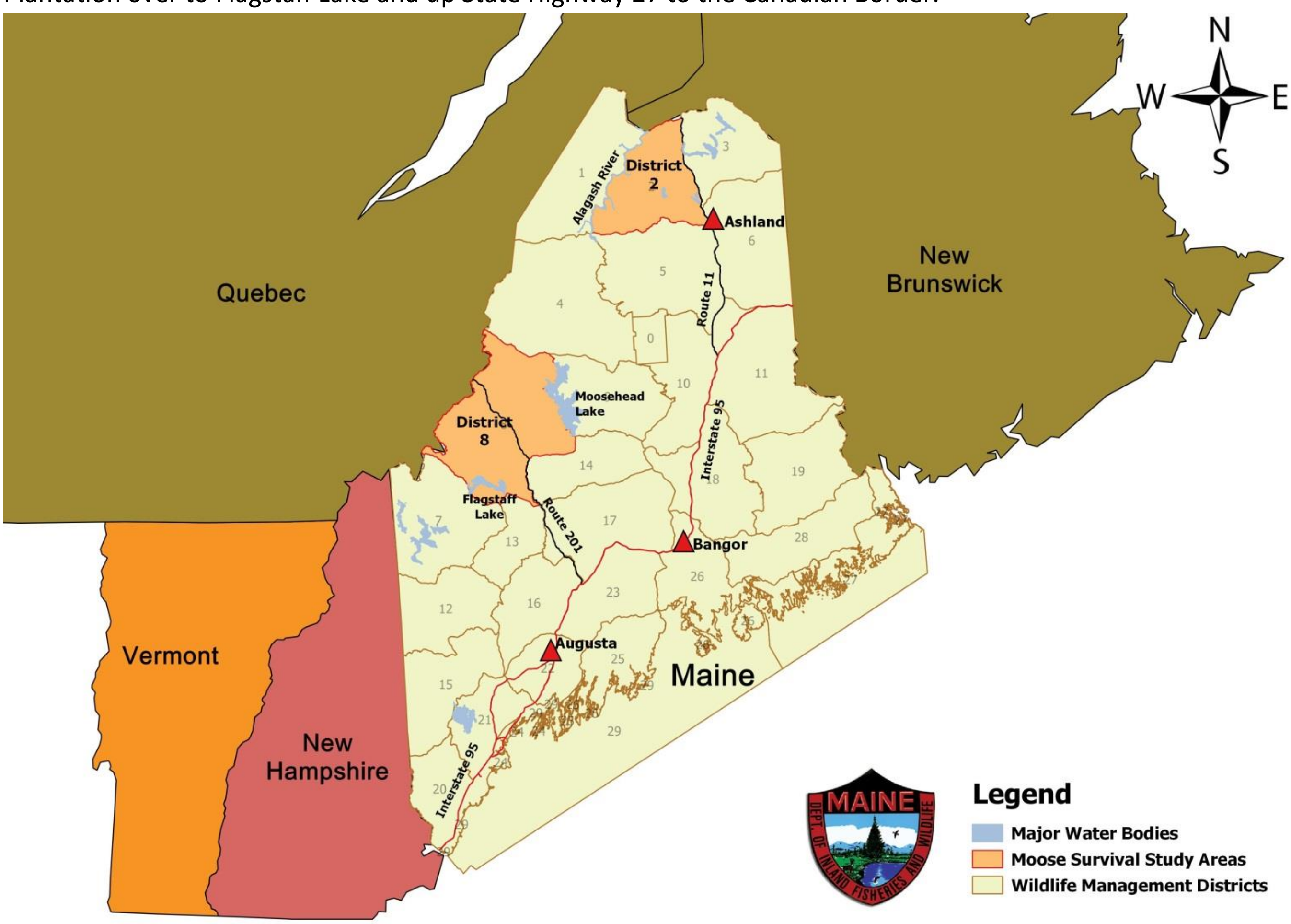

Figure 1. Adult cow and calf moose survival study area.

METHODS

CAPTURE: Moose were primarily captured during January each year using net-gunning; AeroTech-2014/15 and Native Range Capture Services-2016-2020) out of a Hughes 500 or Robinson R44 rotary aircraft (Figure 2), respectively. To bolster sample sizes, MDIFW staff supplemented winter capture efforts within WMD 8 by water capture (July/August) using either a canoe or 16’ motorboat, or by darting roadside from a vehicle (December). All moose were fitted with Vertex Survey Collars (Global Positioning System (Vectronics Aerospace GmbH GPS)/Very High Frequency (VHF)). These collars acquired up to 2 GPS fixes/day spaced 12 hours apart. VHF signals turned on daily during daylight for 12 hours. Transmitters emitted a mortality signal whenever a collar remained still for 6 hours.

Whole blood (6ml), serum (24 ml), and fecal pellets were collected from most net-gun captured moose. Biological samples were not collected from water-captured moose (see below). All moose were ear-tagged (Duplex 2-piece Hog Max) for subsequent ground identification and future recovery. Body condition was subjectively scored along a continuum (very thin to fat). Winter tick counts on shoulder and rump were conducted per MDIFW protocol (Appendix 1).

Figure 2. Restraint and processing of twin calves (Native Range Capture Services in WMD 8, January 2017).

Calf Weights: Beginning in 2016, all calves (~8 months old) were weighed at capture by Native Range using a helicopter-long line with “flak jacket” to restrain and protect them. Capture weights were compared to weights at mortality to provide an assessment of changes in body condition (% weight loss).

Necropsies: A mortality signal triggered a field search for the deceased moose via GPS fix and/or standard ground-based telemetry. Responders investigated mortality signals within 12-48 hours of detection. In most cases field necropsies were performed and photographs of the carcass and lesions were taken (both inside carcass and after removal of affected organ). Signs distinguishing scavenging and predation were noted and documented by photograph. Tissue and parasite samples from all major organs (lung, liver, kidney, intestine, spleen, pancreas, rumen-reticulum-abomasum-omasum, heart, brain, cecum, gonads, and major lymph nodes) as well as femur fat were collected and examined from 2014-2020. Fresh fecal samples extracted from the intestinal tract were placed in whirl-paks. A canine tooth was collected if an adult's age at capture was unknown. Hair samples were collected for corollary studies on genetics (Rosenblatt 2022). Assessment of body condition was done using femur fat content based on a visual scale of white-tailed deer femur fat (Appendix 2) and a qualitative index based on Franzmann (2007). Tissue samples were preserved in 10% buffered formalin and a ~100 mg piece each of fresh liver and kidney were sectioned and later refrigerated for submission and cataloguing for laboratory processing and subsequent pathology by the University of Maine Veterinary Diagnostic Lab (UMVDL). Beginning in 2017, we included an assessment of winter tick life stages, relative percent of engorged winter ticks and a schematic assessment of winter tick induced hair loss (Samuel 1986) to improve characterization of winter tick infestation levels and refinement of our necropsy protocols.

Moose Health Assessment and Screening: Whole blood and serum were collected on adult cows and calves at capture (winter only) by venipuncture of the jugular vein. Blood and serum were placed in clot activator and Ethylenediamine tetracetic acid (EDTA) vacutainer tubes. Samples were cooled until transport to the UMVDL, and slides were prepared for blood smears as soon as feasible. Fecal samples were collected at capture and sent to the UMVDL for analysis of internal parasites. Blood and fecal sample analyses (Table 1) were conducted by the University of Maine (Complete Blood Count and Fecal Flotations), Cornell University Diagnostic Center (Bacteriology and Blood Chemistry Panels), and Michigan State University Diagnostic Lab for population and animal health metrics (Heavy Metals).

Table 1. Maine Moose Capture Sample Screening and Testing List.

TEST	INDICATION	SAMPLE
COMPLETE BLOOD COUNT	BODY CONDITION/ANEMIA	WHOLE BLOOD
TOXIC ELEMENTS	CONCENTRATION LEVELS	WHOLE BLOOD
LARGE ANIMAL PANEL W/ELECTOLYTES	CHEMICAL LEVELS	BLOOD SERUM
SERUM TRACE NUTRIENT PANEL	MICRONUTRIENT ANALYSIS	BLOOD SERUM
FECAL FLOTATION	PARASITE LOADS	FECALS
McMASTERS	TREMATODE EGG COUNTS	FECALS
BAERMANN	NEMATODE LOAD	FECALS

NEONATE MONITORING: Beginning in May 2014, staff annually identified and mapped clustered GPS location points of adult females to determine parturition. In addition, pregnancy tests (Biopryn, 2014-2016, 2018) using serum collected at winter capture from adult females was used to predict potential calving. Each female was stalked to gain direct, undetected observations using the following protocol developed by the University of New Hampshire and New Hampshire Fish and Game Department. Observation of prime aged cows (3+) were prioritized over younger cows based on MDIFW pregnancy data (corpora lutea) and time constraints.

- To measure productivity (fecundity: calves produced per cow), radio-collared cows were stalked on foot (walk-in) and observed at regular intervals 2-3 times weekly from 1 May-31 July or until birth occurred (Musante 2006, Scarpitti et al. 2007). Parturition date was assigned by backdating from the estimated age of neonates; calves are aged as <1 day-old (0 days), 1 day-old, 2-day-old, 3-7 day-old (5 days), or >7 days based on coordination, mobility, wet or dry appearance, and presence of an umbilicus (Larsen et al. 1989). In addition, clustered location points of adult cows, observation of the birth site, calf beds or tracks, and behavior and posture of cows were used to assess reproductive status.

- Neonatal and postpartum mortality was measured by visual observations, monitoring calves 1-2 times weekly for ~2 months post-partum. Sign such as beds, tracks, fecal matter, birthing membranes, and evidence of predation were noted. Observation of cow behavior and evidence (e.g., tracks and beds) at location sites helped to establish fate of the calf (Musante 2006). Cows were observed >3 separate times after initial absence of the calf before assigning it as a mortality. The mortality date was set as the midpoint between the last observation date and first absence date.

RESULTS

Capture and Handling: In the first year of the WMD 8 study (2014), we fitted GPS collars to 36 adult cows and 30 calves (Table 1). Based on project costs and significant adult cow losses, we adjusted sample sizes to 35 adult cows and 35 calves each year thereafter. With the addition of the WMD 2 study area in 2016, the number of moose captured annually increased. At the completion of these studies, we had captured and GPS-collared 545 moose, including 128 adult cows and 417 eight-month-old calves (Table 2). Nearly all captures (n=524) were by aerial net-gunning during the month of January.

Table 2. Sample sizes of GPS marked moose at capture by study area and year in Maine, 2014-2020.

Capture Year	Age at Capture	District	Total	Female	Male
2014	Adult	8	36	36	
2014	Calf	8	30	15	15
			66	51	15
2015	Adult	8	5	5	
2015	Calf	8	35	23	12
			40	28	12
2016	Adult	2	36	36	
2016	Calf	2	35	21	14
2016	Calf	8	36	20	16
			107	77	30
2017	Calf	2	37	19	18
2017	Adult	8	6	6	
2017	Calf	8	36	18	18
2018	Calf	2	36	21	15
2018	Adult	8	21	21	
2018	Calf	8	33	18	15
			90	60	30
2019	Adult	2	12	12	
2019	Adult	8	12	12	
2019	Calf	2	34	18	16
2019	Calf	8	35	17	18
			93	59	34
2020	Calf	2	35	15	20
2020	Calf	8	35	17	18
			70	32	38

2014-2020 Totals	Age at Capture	District	Total	Female	Male
	Adult	2	48		
		8	80		
			128		
	Calves	2	177	94	83
		8	240	128	112
	Total		*417*	*222*	*195*
	Total Moose		**545**		

Calf Weights: Weights were determined for 313 eight-month-old calves (Table 3) at capture in January from 2016-2020 and are summarized by year, WMD and sex.

Table 3. Mean January weights of eight-month-old moose calves in Maine, 2016-2020 by WMD, sex and sample size (n=313).

	2016	**2017**	**2018**	**2019**	**2020**
WMD 2 Female	406.1 (17)	412.6 (18)	392.8 (18)	390 (18)	370.7 (14)
WMD 2 Male	425 (12)	450.8 (17)	430.7 (14)	410.6 (16)	406.7 (18)
WMD 8 Female	426.4 (16)	389.6 (13)	389.4 (17)	391.2 (17)	368.75 (16)
WMD 8 Male	430 (11)	428.9 (12)	416.7 (12)	424.4 (18)	408.9 (19)
Female	416 (33)	402.6 (31)	391.1 (35)	390.6 (35)	369.7 (30)
Male	427.4 (23)	441.7 (29)	424.2 (26)	417.9 (34)	407.8 (37)
All	420.7 (56)	421.1 (60)	405.2 (61)	404 (69)	391.8 (67)

Two ANOVAs were fit to evaluate differences in weights between WMDs, sex, and years. The first model included an interaction term (district × year) to evaluate if weights differed between districts each year and the second evaluated sex-specific differences in weights between WMDs (A. Siren, MDIFW unpublished data). The results from this analysis indicate that there was some variation in annual weights that could be explained by year and sex, yet there were no sex-based differences between WMDs (i.e., male vs. male and female vs. female calf weights did not vary between WMDs). The results are highlighted below:

- Weights were lower in WMD 8 (406 ± 4 lbs.) compared to WMD 2 (410 ± 4 lbs.) but only statistically lower in WMD 8 during 2017 (β = 37.341, SE = 18.632, P = 0.046), and weights declined in both WMDs during the 5 years of sampling.
- Male calves (425 ± 7.7 lbs.) were significantly heavier (β = 29.755, SE = 7.702, P < 0.001) than females (395 ± 5 lbs.).
- Weights were similar (P = 0.854) within sex in both WMDs (i.e., males weighed the same in WMD 2 and 8 as did females).

MORTALITIES: We documented 298 mortalities over the course of the project (Table 4). The highest number of mortalities (215 or 72%) were calves prior to or near their 1st birthday. Of the 83 documented adult mortalities, 22 (26.5%) were legally harvested or a result of wounding losses not recovered by the hunter (n = 2). The highest percentage of mortalities occurred during the month of April (53%, Figure 3). March was the second highest month of mortality at 16%. Eighty-nine percent of the mortalities occurred between February and May. Two additional mortalities were attributed to capture.

During the five concurrent years, overwintering calf mortality in WMD 2 averaged 20% less than overwintering calf mortality in WMD 8. In 2019, however, calf mortality was equal in both WMD 2 and 8. Adult mortality, other than legal harvest, remained low in both units except for 2014 in WMD 8 (43%). In 2019, legal harvest of moose was at its highest level in WMD 2 comprising 59% of annual mortality.

Table 4. Moose mortalities by year and age class (n=298) in WMD 2 and WMD 8, 2014-2020.

	WMD 2			WMD 8		
	Adult	Calves (Mort. Rate)	Calves Collared	Adult	Calves (Mort. Rate)	Calves Collared
2014	NA	NA	NA	13	22 (73%)	30
2015	NA	NA	NA	5	21 (60%)	35
2016	6	18 (51%)	35	5	26 (72%)	36
2017	3*	11 (30%)	37	6	20 (56%)	36
2018	2*	10 (28%)	36	1*	15 (45%)	33
2019	17*	23 (68%)	34	12*	23 (66%)	35
2020	4*	5 (14%)	35	9	19 (54%)	35
Total	32	67 (38%)	177	51	146 (61%)	240

*Including legal harvest

WINTER TICK LOADS AT CAPTURE

Dunfey-Ball (2017) demonstrated that winter tick loads of >36.9 ticks on fall-harvested moose measured as the sum of four rump and four shoulder transects could predict a >50% probability of a spring winter tick epizootic of overwintering calves. Total winter tick counts on live calves in January were higher every year, except 2017, in WMD 8. Dunfey-Ball theorized that the threshold of 36.9 ticks indicates that as tick numbers increase, mortality increases exponentially.

Table 5. The summed average of shoulder and rump winter tick transect counts by WMD and year on 8-month-old calves at capture, 2016-2020.

	2016	2017	2018	2019	2020
WMD 2	62.2	44.2	19.9	29	10.3
WMD 8	71.1	43.2	22.5	39.7	28.7

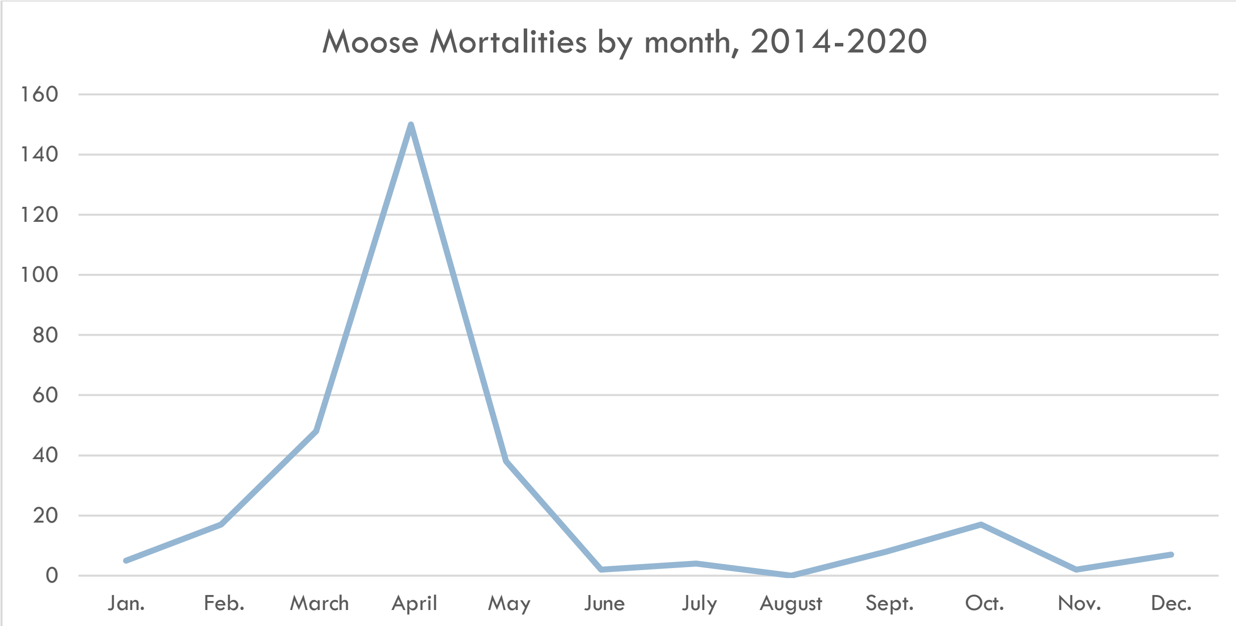

Figure 3. Moose mortalities (n = 298) by month in WMD 2 and WMD 8, 2014-2020

Calf weight loss at death: Weight at capture and at death were recorded for 133 calves across both study areas, 51 in WMD 2 and 82 in WMD 8 beginning with the 2016 capture year (Table 6). Weight loss by sex and year as well as pooled data by sex is described in Table 5.

Table 6. Percent weight loss at death of calves (n) in WMD 2 and WMD 8, 2016-2020.

	2016	2017	2018	2019	2020
WMD 2 Female	27 (8)	29 (3)	21 (3)	25 (8)	25 (3)
WMD 2 Male	26 (4)	33 (4)	31 (5)	29 (11)	29 (2)
WMD 8 Female	22 (12)	22 (10)	16 (9)	21 (11)	27 (6)
WMD 8 Male	23 (9)	26 (5)	22 (3)	21 (9)	25 (9)
Female	24 (20)	24 (13)	17 (12)	23 (19)	27 (9)
Male	24 (13)	29 (9)	28 (8)	25 (20)	26 (11)
All	24 (33)	26 (22)	21.5 (20)	24 (39)	26 (20)

Moose Health Assessment and Screening: An important product of moose capture is the ability to assess physiological condition of moose by sampling blood and feces. Quantifying survival rates includes establishing baseline values for moose health, as well as proximate (immediate) and/or ultimate (factors that predisposed the animal to death) causes of mortality. Biological samples (e.g., liver) taken at mortalities were analyzed for malnutrition, toxic elements, parasites, and diseases using a variety of hematological, chemistry, and biological identification techniques (Jones 2016). Most published values of these elements (except internal parasite data) come from Norwegian (*Alces alces alces*), Alaskan (*Alces alces gigas*) or Shiras (*Alces alces shirasi*) moose, which are separate subspecies that exist in different habitats than Maine moose.

Data were collected on 365 captured moose (95%) (some capture events precluded collection of blood and/or feces). Jones (M.S., University of New Hampshire 2016) analyzed data from the 2014-2016 capture for New Hampshire and Maine. Both states utilized the same capture crews, blood and fecal sampling technique and subsequent analyses. Jones concluded that there was no significant physiological impairment of moose at the time of capture. Calves (~10-11 months) that died during this period were in poorer health than surviving moose, suggesting that winter tick was a significant driver of mortality. Low serum iron levels collected from liver samples were an indication of anemia and poor body condition.

A detailed assessment of the health and condition of GPS collared moose from WMD 8 between 2014-2016 is described in Jones et al. (2019). Similar analyses were done in WMD 8 from 2017-2019 as well as WMD 2 from 2016-2019. Overall values were not statistically different from the data reported in Jones et al.

ADULT COW PRODUCTIVITY AND NEONATE/CALF SURVIVAL: Over the course of the project, 417 adult cows (yearling and older) were monitored from mid-May until the end of July to determine calving rates (Table 7). Calves were observed weekly during the summer to determine survival rates. Of 160 documented calves, 88% survived until August. Nearly all neonates were observed as singletons; only 3 sets of twins were recorded over the 7 years of study. Of the 1 set of twins documented in 2017 in WMD 8, both calves died. In 2016 and 2019 in WMD 2, 1 of the twins in each pair did not survive.

Table 7: Cow pregnancies and survival rates of neonates by WMD and capture year in Maine WMD 8 and 2, 2014-2020.

WMD	Year	Adult Cows	Yearling	Verified Pregnancy	Calves	#Twins (Sets)	Died	Survived	Summer Survival
8	2014	20	6	20	11	0	1	10	0.91
	2015	31	12	3	13	0	0	13	1.00
	2016[a]	26	11	na	14	0	2	12	0.86
	2017	28	5	na	15	1	2	13	0.87
	2018	20	5	7	9	0	0	9	1.00
	2019[b]	32	6	na	17	0	4	13	0.76
	2020	33	4	na	17	0	1	16	0.94
2	2016[a]	26	0	14	17	1	3	14	0.82
	2017	27	6	15	8	0	3	5	0.63
	2018	25	7	na	8	0	1	7	0.88
	2019	29	15	na	18	1	1	17	0.94
	2020[c]	36	7	na	13	0	1	12	0.92
	All	333	84		160	3	19	141	0.88

[a]2016: WMD 8-2 adults died (15076 and 14026)
[b]2019: 2 adults died WMD 8-19441 had calf, WMD 2-19393
[c]2020: WMD 2-2 adults died 17240 and 19392 (1 calf)

DISCUSSION

MORTALITY: Based on previous telemetry work conducted by New Hampshire Fish and Game (2001-2006), we anticipated losses associated with winter tick infestations during the project. Indeed, preliminary lab results from mortality tissues, blood chemistry panels and laboratory necropsies implicated winter ticks as the cause of massive weight loss and anemia. Overwintering calf losses (Table 4) in WMD 8 ranged from a low of 45% (2018) to 74% (2016 and 2019). WMD 2 experienced lower rates of annual mortality than that of WMD 8. In 2019 however, WMD 2 experienced an exceptionally high level of mortality (70%, nearly equal to 74% documented in WMD 8) due to measurable snow and cold that arrived early in October in both study areas. These conditions are believed to shorten the fall winter tick questing period resulting in lower tick densities entering winter. However, snow depths accumulated throughout the season with an unconsolidated snow profile that likely contributed to increased energy drains for animals in both study areas. Early deep snows that remained unconsolidated for several months with more than 3 feet that remained well into May, reduced moose winter home ranges (MDIFW unpublished data) contributing to difficult wintering conditions with decreased mobility. We documented adult mortalities in both early winter (January- February) as well as late season (April-May) in 2019, including 3 cows with full term fetuses; this was unusual relative to the paucity of these events during other years.

With the establishment of the WMD 2 study area in 2016, we were able to compare survival between study areas. Calf mortality rates remained high in WMD 8 over the 7 years of the study (~59%, range: 60%-74%, Table 3), 2014-2020 compared to WMD 2 (38%, range: 20%-68%).

All necropsies were conducted by three IFW staff members with a few minor exceptions. Field responders gained expertise over the course of the project that acted as a constant in our field assessment work and maintained consistency in the collection of data and interpretation of evidence at the mortality site.

Dunfey-Ball (M.S., University of New Hampshire, 2017) examined the relationship between moose densities, tick abundance, and climate in New Hampshire and Maine. His work predicted a non-epizootic (<50% calf mortality) year for 2017 based on 2016 drought conditions towards summer's end resulting in increased mortality of winter tick eggs and a subsequent early snowfall that increased mortality of questing winter tick larvae. Calf mortality rates in WMD 8 surpassed this benchmark at 58% mortality while WMD 2 calf mortality remained low at 24% in 2017.

In 2020, calf mortalities were the lowest in WMD 2 during the 5 years of study (14%). Although winter arrived early and there was measurable snow in November, overall snow depths throughout winter were below average and spring conditions (i.e., receding snow depths) emerged earlier compared to long term trends. Calf mortality in WMD 8 that year was also low (54%) relative to other years.

Summer-calf mortality: Calves have greater vulnerability to mortality factors during the first three weeks of life (neonates). At parturition, calves may be born underweight, have difficulty nursing, or be prone to disease and predation. Patterson (2013) characterized early calf losses due to malnutrition, abandonment, or exposure. In Minnesota calf losses of 68% were directly or indirectly due to wolves (Severud et al. 2015). While Maine does not have wolves, it is important to compare the magnitude of neonate losses in jurisdictions with similar characteristics. Determining the rate and cause of neonate losses is extremely difficult since assessment of birth sites and determination of calf condition at parturition is not feasible and/or highly invasive to the calf and dam.

Monitoring pregnant cows throughout gestation to parturition is intensive, but less invasive than direct collaring of the moose.

The body condition of the adult female during estrus is critical to ovulation rates (Pekins and Adam 1995) and ultimately the success of bringing the fetus to term. Calving and nurturing the neonate to the weaning stage also creates a high energetic demand on the dam. Since adult cows captured during the study were fitted with GPS collars, daily locations (specifically clustered locations) were used to determine parturition and location (McGraw et al. 2014). From May through the end of July, cow moose were observed to determine the presence of calves. Weekly monitoring of successful cows continued with three consecutive verified sightings of calf presence or absence over the course of the summer. Calving success or loss could not be verified until 3 visuals of cow with calf or cow without calf were completed.

Over the course of the project detecting and verifying newborn calves was difficult. In most years we could not verify more than 50% of the collared adult cows having calves. Thus, either the cow did not calve, or efforts and technique failed to result in verification of a calf at heel. Given the challenges of detecting calves specifically within 24 hours of parturition and given cow-with-calf behavior to avoid detection, it is likely we missed calves that were present or missed calves that died at birth. We conclude that the numbers of calves detected and their survival through summer are likely conservative estimates; our assessment of fecundity (calves/cow) is also likely conservative. Calf survival through summer was high (88%) across both research units (Table 6). Though time consuming and labor intensive, walk-in observations (stalking) were the best method to monitor calving since aerial observation is largely hindered by dense canopy and thick vegetation that is typical of calving habitat in northeastern states (Scarpitti et al. 2007).

Annual collection of corpora lutea (CL) from hunter-harvested cows provides additional insight and support of poor productivity in Maine moose. Corpora lutea rates less than 1.17/cow in North American populations are considered productive (Boer 1992) but CL rates at or below 0.88 demonstrate a population above carrying capacity. CL rates for Maine have been consistently at or below 1.00 CL/cow (MDIFW unpublished data) and at or near 0.88 recently. We hypothesize that this is in part due to annual winter tick loads and drain on pregnant cow body mass as outlined in Pekins (2020). Furthermore, low twinning rates provide further documentation of depressed reproduction. During the late 1980's, a period of moose recolonization in Maine, twinning rates reached >50% (MDIFW data); rates of twinning in recent years are <25% (MDIFW harvest data 2010-2020). As mentioned earlier productivity in adult cows is directly attributed to gain and maintenance of annual body mass. Annual winter tick loads exert substantial stress to moose especially pregnant cows that must rely on mobilization of fat reserves to maintain not only their own mass but to nourish the development of their fetus during the high point of adult winter tick feeding (March-April).

CONCLUSION

MDIFW assessed adult cow and calf survival in two wildlife management districts for 7 years. We examined a large sample size of moose mortalities with determination of death on most animals. We concluded that the primary driver of overwintering calf mortality was winter tick infestations. We concluded that successive year winter tick infestations not only lead to repeated epizootics but that winter tick loads play a significant role in depression of reproduction by adult cows. In addition, winter tick infestations likely create a lag effect in that the cycle of annual infestations, subsequent blood loss, and loss of body condition result in animals entering summer in poor condition who then have less time and ability to gain back losses before senescence of vegetation in the fall (Pekins 2020). A high number of moose carry some annual level of winter tick infestation that creates a negative effect on body condition during the critical winter-spring period. The verification of consecutive winter tick infestations and its impacts on moose has resulted in a population of seasonally unthrifty moose with poor reproductive capabilities. This work confirmed that Northern New England is the only region in the global moose range experiencing consecutive winter tick epizootics implicating the interaction of climate change, moderate to high moose densities, and high winter tick abundance.

MANAGEMENT IMPLICATIONS

Given the ecological, economic, cultural, and aesthetic importance of moose in Maine, public interest in the health and conservation of moose is significant. The 2017 MDIFW Big Game Management Plan included considerable public consultation and emphasized managing moose for population health. Taking management actions to decrease winter tick impacts on overwintering calves and increasing cow productivity are strategies for improving moose health. However, there are scant alternative actions for reducing winter tick abundance. Moose managers acknowledge that low density moose populations exhibit higher levels of reproduction and less incidence of disease and parasitism. To this end future management of moose is directed at experimentally reducing moose populations in management subunits to determine if lowering moose numbers can help break the winter tick infestation cycle or improve overwinter calf survival. In addition, we recommend continued research on winter tick ecology as it relates to forest management and timber harvest regimes. Manipulation of habitat to reduce winter tick abundance and/or high moose use may provide additional alleviation of the problem but will require more research to identify these avenues and mechanisms.

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5. Media Communications

Year	Organization	Topic	Media
2021	The Wall St. Journal	Moose and Adaptive Unit	News
2021	WIRED	Moose and Adaptive Unit	Web News
2021	The Today Show-NBC	Moose and winter Tick	Television
2021	Natural History Magazine	Moose and Winter Tick	Magazine
2021	Q106.5	Adaptive Moose Hunt	Radio/Web
2021	The Piscataquis Observer	Moose Hunt and Adaptive Unit	Newspaper/Web
2021	Portland Press Herald	Adaptive Moose Hunt	Newspaper/Web
2021	The Maine Outdoors	Adaptive Moose Hunt	Radio
2021	The Maine Sportsmen	Adaptive Moose Hunt	Magazine/Web
2021	Northwoods Sporting Journal	Adaptive Moose Hunt	Magazine/Web
2021	Bangor Daily News	Moose and Winter Tick	Newspaper/Web
2020	207-NewsCenterMaine	Moose Survival Project	Television
2019	Maine Public-Maine Calling	Moose Survival Project	Radio
2018	BBC-Autumn Watch	Moose Research	Television
2018	Bangor Daily News	Moose Research	Newspaper/Web
2018	Yankee Magazine	Moose Research	Magazine
2017	Maine Outdoors	Moose Research/Mgt	Radio
2017	Inside Climate News	Moose Research	Internet
2017	Portland Press Herald	Moose Research	Newspaper
2016	New York Times	Moose Research	Newspaper
2016	Boston Globe	Moose Research	Newspaper
2016	Bangor Daily News	Moose Research	Newspaper
2016	Portland Press Herald	Moose Research	Newspaper
2016	WMTW (Portland)	Moose Research	Television
2016	WCSH (Portland)	Moose Research	Television
2015	WMTW (Portland)	Moose Research	Television

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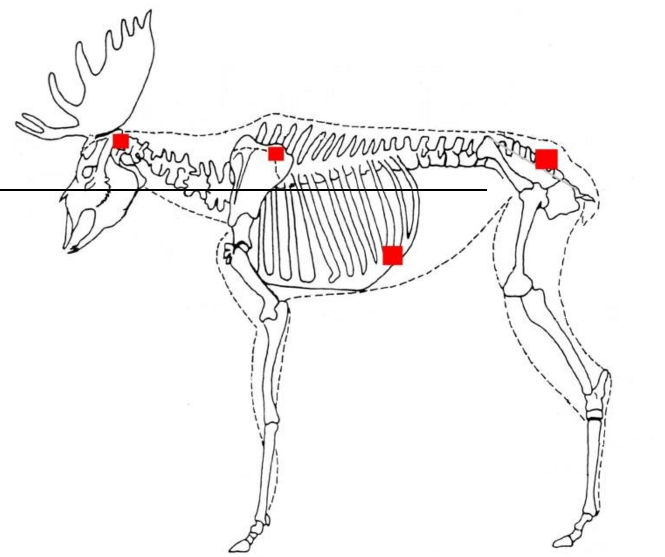
APPENDIX 1.

MDIFW WINTER TICK COUNT PROTOCOL

Monitoring technique:

This involves counting ticks on four 10 cm long transects on each of 4 standard areas of the moose (16 transects). Two locations are areas that usually harbor many ticks and 2 are areas with fewer ticks. Poor tick areas are included during the development phase because virtually all moose have ticks so only counting on the places most likely to harbor ticks may not be very indicative of overall tick load.



Protocol: count during the October season only, with exception made to IFW staffed November stations.

Equipment: pick for parting hair and measuring, magnifying glass with light optional. If pick is not provided, measure and mark 10cm on pencil or other straight utensil that can serve for parting and measuring

Specimens: To be used in the tick count, a moose must have been killed 2-5 hours ago, and not have significant hair loss from dragging on the side to be counted. In addition, use common sense in deciding if the moose is in a reasonable position to perform the counts and if you can do so without holding up the station unreasonably.

Areas for counting: Locate the 4 areas for counting as indicated on the diagram provided. Use the skeletal structures to locate the plots.

Transects: within each area, create four 10 cm transects by parting the hair. Transects should be about 2 cm apart. The quickest way to do this is to part the hair w/ the marked stick at right angles to hair direction. The sticks are marked at 10cm.

Locations of tick monitoring plots.

- On the neck at the base of the skull,
- Upper edge of shoulder blade,
- Rump: midway between hip bone and base of tail,
- Edge of rib cage

Counting: Count all ticks you can see along the 10 cm part including those that are visible near the part.

Tick activity: Please note if ticks are leaving the carcass while you are counting.

This is what a 10 cm transect line looks like when parting the hair.

Below are the life stages of the winter ticks. You will be counting larvae!

Larva

Engorged Nymph

Female

Unengorged Adults

Appendix 2.

White-tailed deer femur fat index.

White-tailed Deer Femur Marrow Categories[1]

Appearance/Texture[2]	% Fat	Field View
White/off white solid; fatty feel	90-100%	
White with pink spots or other white/pink mix; solid; fatty feel	80-90%	
Pink solid; fatty feel	65-80%	
Red solid; fatty feel	45-65%	
Red soft; moist; losing fatty feel	20-45%	
Dark red; liver color; soft; fatty feel almost gone	10-20%	
Red gelatinous; no fatty feel; high moisture content	3-10%	
Red/orange gelatinous; translucent; no fatty feel; "jello"-like	0-3%	

[1]Assumes cooled carcass and marrow from middle third of femur bone.

[2]Some specimens may exhibit a yellow-orange range of color instead of pink-red; in these cases, use darkness of color, texture and degree of fatty feel as guides.

Appendix 3.

Dressed weight of cow moose harvested in New Hampshire and corresponding ovulation rates based on corpora lutea counts, 1988-1994.

Dressed Cow Moose Weight		
Kilograms (kg)	**Pounds (lb)**	**Corpora Lutea (cl)**
<200 kg	400 lb	not reproductive
200-250 kgs	400-551 lbs	1 cl
251-275 kgs	553-606 lbs	1.5 cl
>275 kgs	>606 lbs	2 cl

Appendix 3. Weight loss in calves by WMD, sex, and year, 2016-2020.

WMD	Sex	Capt. Weight	Mort Weight	No. Loss	% Loss	Year	WMD	Sex	Capt. Weight	Mort Weight	No. Loss	% Loss	Year
8	F	400	343	57	14%	2016	8	F	390	299	91	23%	2018
8	F	450	344	106	24%	2016	8	F	380	334	46	12%	2018
8	M	350	287	63	18%	2016	8	F	380	294	86	23%	2018
8	F	430	347	83	19%	2016	8	F	390	319	71	18%	2018
8	M	390	257	133	34%	2016	8	F	320	281	39	12%	2018
8	M	440	373	67	15%	2016	8	F	420	395	25	6%	2018
8	F	330	284	46	14%	2016	8	F	420	367	53	13%	2018
8	M	400	313	87	22%	2016	8	F	280	215	65	23%	2018
8	F	470	351	119	25%	2016	2	F	370	316	54	15%	2019
8	M	380	322	58	15%	2016	2	F	420	306	114	27%	2019
8	F	388	297	91	23%	2016	2	F	370	278	92	25%	2019
8	M	480	390	90	19%	2016	2	F	400	305	95	24%	2019
8	F	350	306	44	13%	2016	2	F	370	275	95	26%	2019
8	F	495	319	176	36%	2016	2	F	400	273	127	32%	2019
8	M	460	330	130	28%	2016	2	F	450	364	86	19%	2019
8	M	440	302	138	31%	2016	2	F	410	258	152	37%	2019
8	F	430	317	113	26%	2016	2	M	440	296	144	33%	2019
8	F	390	300	90	23%	2016	2	M	390	284	106	27%	2019
8	F	470	345	125	27%	2016	2	M	430	300	130	30%	2019
8	F	400	299	101	25%	2016	2	M	410	285	125	30%	2019
2	F	398	270	128	32%	2016	2	M	390	294	96	25%	2019
2	F	348	259	89	26%	2016	2	M	400	260	140	35%	2019
2	F	460	327	133	29%	2016	2	M	400	315	85	21%	2019
2	F	390	266	124	32%	2016	2	M	470	291	179	38%	2019
2	M	470	346	124	26%	2016	2	M	380	285	95	25%	2019
2	F	400	340	60	15%	2016	2	M	410	317	93	23%	2019
2	F	420	290	130	31%	2016	2	M	370	259	111	30%	2019
2	M	430	359	71	17%	2016	8	F	370	289	81	22%	2019
2	M	310	214	96	31%	2016	8	F	370	309	61	16%	2019
2	F	430	272	158	37%	2016	8	F	400	309	91	23%	2019
2	M	450	310	140	31%	2016	8	F	490	373	117	24%	2019
2	F	320	278	42	13%	2016	8	F	260	207	53	20%	2019
8	M	480	374	106	22%	2016	8	F	410	312	98	24%	2019
2	F	416	304	112	27%	2017	8	F	420	341	79	19%	2019
2	F	370	274	96	26%	2017	8	F	390	300	90	23%	2019
2	M	461	298	163	35%	2017	8	F	350	318	32	9%	2019
2	M	480	278	202	42%	2017	8	F	370	272	98	26%	2019
2	F	319	202	117	37%	2017	8	F	380	294	86	23%	2019
2	M	435	312	123	28%	2017	8	M	420	384	36	9%	2019
2	M	400	286	114	29%	2017	8	M	360	296	64	18%	2019
8	F	401	346	55	14%	2017	8	M	450	332	118	26%	2019

8	M	440	317	123	28%	2017	8	M	370	286	84	23%	2019
8	F	354	276	78	22%	2017	8	M	490	412	78	16%	2019
8	M	335	272	63	19%	2017	8	M	440	354	86	20%	2019
8	M	406	307	99	24%	2017	8	M	420	321	99	24%	2019
8	M	453	330	123	27%	2017	8	M	440	316	124	28%	2019
8	F	370	273	97	26%	2017	2	M	330	247	83	25%	2020
8	M	415	274	141	34%	2017	2	F	250	208	42	17%	2020
8	F	400	312	88	22%	2017	2	M	320	234	86	27%	2020
8	F	350	255	95	27%	2017	2	M	230	155	75	33%	2020
8	M	448	350	98	22%	2017	2	F	330	222	108	33%	2020
8	F	385	322	63	16%	2017	8	M	410	326	84	20%	2020
8	F	374	301	73	20%	2017	8	F	290	240	50	17%	2020
8	F	340	247	93	27%	2017	8	M	470	388	82	17%	2020
8	F	397	308	89	22%	2017	8	F	450	333	117	26%	2020
2	M	470	317	153	33%	2018	8	F	370	270	100	27%	2020
2	M	360	240	120	33%	2018	8	M	460	304	156	34%	2020
2	F	370	338	32	9%	2018	8	M	340	268	72	21%	2020
2	M	440	293	147	33%	2018	8	M	380	258	122	32%	2020
2	M	390	257	133	34%	2018	8	M	320	229	91	28%	2020
2	M	430	334	96	22%	2018	8	F	430	276	154	36%	2020
2	F	430	378	52	12%	2018	8	M	430	304	126	29%	2020
2	F	390	220	170	44%	2018	8	M	370	283	87	24%	2020
8	M	410	343	67	16%	2018	8	M	330	258	72	22%	2020
8	M	420	337	83	20%	2018	8	F	310	233	77	25%	2020
8	M	340	238	102	30%	2018	8	F	410	274	136	33%	2020
8	F	360	307	53	15%	2018				**ALL**	97	24%	