A HISTORY OF MOOSE MANAGEMENT IN UTAH

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ABSTRACT: During the first half of the 20th century a moose (*Alces alces*) population gradually established itself on the North Slope of Utah's Uinta Mountains from founders in the Greater Yellowstone Ecosystem. Formal management of the species commenced with an aerial survey conducted in 1957, and the first legal hunt in 1958. From this small initial population moose have expanded into other areas of northern Utah and, augmented by transplants, the statewide population has increased to an estimated 3,200 animals as of 2009. In the northern portion of the state moose appear to prosper in riparian willow (*Salix sp.*) habitats as well as upland shrub-dominated and forested habitats. However, there are indications that these herds are at or approaching carrying capacity. Management programs have included regular aerial surveys, harvest regulation, transplants, and dealing with "nuisance" animals along the urban-wildland interface. Since 1958 a total of 6,119 moose (bulls and cows) have been legally harvested, averaging 288 animals annually in 2004-2008. Since 1973 a total of 345 moose have been translocated within Utah and an additional 115 animals moved to Colorado. These transplants have resulted in disparate success with starter populations generally failing to achieve viability in central and southern Utah. Poaching, predation by cougars (*Puma concolor*), and to a lesser extent disease have contributed to losses in southern target populations. The limited success of these efforts raises questions regarding the viability of populations in areas with high summer temperatures as well as the specter of climate variation on the persistence of southern populations, generally. Several research projects have been conducted on moose in Utah. Early studies on the Uinta North Slope focused on the nutritional quality of key browse species and the determination of carrying capacity, and subsequent investigations included the effects of experimental manipulation of bull-cow ratios on calf recruitment, and telemetry-based survival studies of transplanted herds. The future of moose in Utah is discussed in light of potential limiting factors including climate change.

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Moose (*Alces alces*) are thought to be a fairly recent addition to the New World fauna, with the oldest North American records dating to Alaska during the late Pleistocene (Hundertmark et al. 2003). The lack of fossil evidence from the central and southern Rockies suggests that moose in Utah are the result of an historical southward range extension of the Shiras subspecies. As noted by Houston (1968), the first sightings of moose in Yellowstone National Park occurred in the late 1860s. In Utah, occasional sightings of individual moose occurred throughout the first half of the 20th century (Barnes 1927). A combination of circumstances made the Uinta Mountains the most likely location for establishment of a resident population in the state as the result of animals dispersing from southern Wyoming. These factors include the predominant east-west orientation of the range (Fig. 1), the abundance of riparian and subalpine habitat, and connectivity with Teton-Yellowstone populations via the Salt River Mountains and the Wyoming range. Whether recolonization of the area by beaver (*Castor canadensis*), including transplant efforts (West and Rasmussen 1947), played a role in the southern expansion of moose is not clear (Rudersdorf 1952, Van Wormer 1967, Wolfe 1974).

The Utah moose population is significant for 2 reasons. First, it represents the only occurrence of the species in the Great Basin ecoregion; secondly, it has the distinction as being the southernmost naturally-established moose population within the species' North American distribution. As such, moose in Utah are subject to a suite of constraints in common with other populations of *A. a. shirasi* in the interior western United States, specifically southeastern Idaho, and southwestern and western Wyoming. These include summer temperatures exceeding 20° C and limited availability of riparian and lacustrine habitats, with consequently greater occupancy of upland habitats. In addition, the areal extent of winter ranges may be limited by snow depth at higher elevations, and in some locations further exacerbated by urban encroachment. Other factors include substantial habitat overlap with wild and domestic ungulates on both summer and winter ranges, with implications for predation, disease transmission, and interspecific competition.

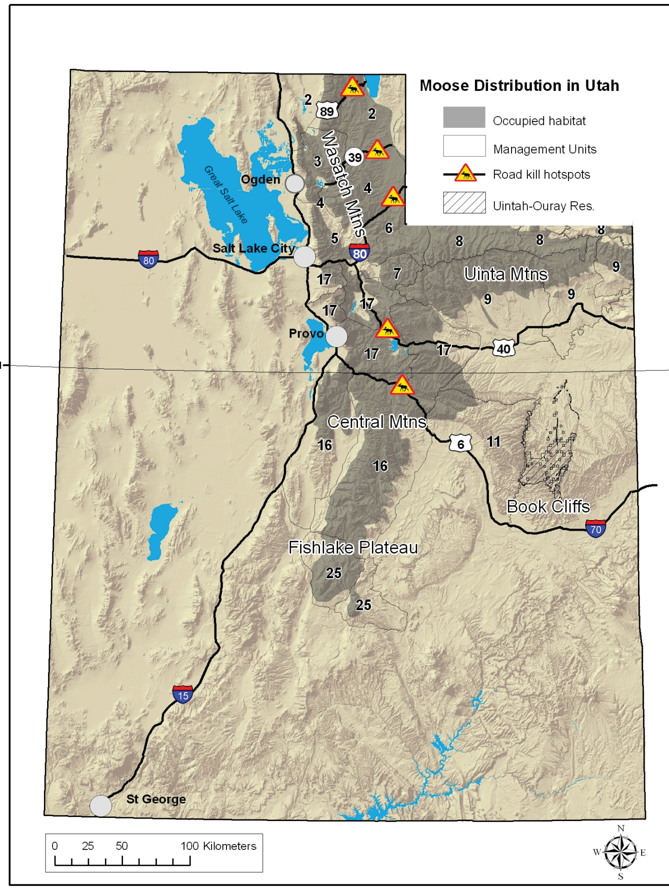

Fig. 1. Salient Utah topographic features and Big Game Management Unit Boundaries. 2 = Cache; 3 = Ogden; 4 = Morgan-South Rich; 5 = East Canyon; 6 = Chalk Creek; 7 = Kamas; 8 = North Slope; 9 = South Slope; 10 = Book Cliffs; 11 = Nine Mile, Anthro; 16 = Central Mountains; 17 = Wasatch Mountains; 25 = Fishlake, Plateau.

Management of moose in Utah has emphasized the species' relative novelty and trophy status for both consumptive and non-consumptive recreationists. Utah hunting regulations classify moose as a "once in a lifetime species", and populations are managed for high hunter success rates and probability of harvesting a mature bull (ages >4.5 yr); to achieve those objectives, only a limited number of permits are available each hunting season. The Statewide Moose Management Plan (UDWR 2007) specifies 2 primary (and related) goals: 1) to maintain optimum populations … in all suitable habitat, and 2) to assure sufficient habitat is available to sustain healthy and productive populations. The purpose of this paper is to review the history of efforts to manage moose and provide a perspective on the species' future in the state.

METHODS AND DATA SOURCES

Population estimates and trends reported here were derived from periodic mid-winter aerial surveys, the first of which was conducted in 1957 on the Uinta North Slope. These counts were conducted from fixed-winged aircraft (Piper Super Cub and Cessna 180) until 1963, after which helicopters were employed. Procedurally, these surveys are attempts at total coverage of the winter range area, in which the riparian areas of individual drainages are flown and tracks leading out of the drainages followed to locate animals in upland forested areas. Additional surveys commenced in other management units as resident populations became established.

Currently, trend counts on individual units are conducted on a quasi-periodic and rotating basis with an average interval of ~3 years, subject to suitable survey conditions (i.e., snow cover). These counts are conducted in combination with elk (*Cervus elaphus*) surveys using a sightability factor of 80% for both species (Kimball and Wolfe 1974). Annual estimates are interpolated from these counts using computer-assisted projection techniques (POP II). Estimates of the areal extent of moose habitat (mostly yearlong) on the respective herd units were obtained from "expert opinion" of biologists and managers in the various regions. Although subjective, these values were used in conjunction with those for population size to derive density estimates. Estimates of productivity (calves/100 cows) are derived from aerial classification of animals counted during winter surveys. Sex determination among antlerless animals is based on the presence (females) or absence of a white urogenital patch as described by Mitchell (1970).

Hunting bull moose in Utah is considered a "once-in-a-lifetime opportunity", and permits for both sexes are issued on a draw (lottery) system. Harvest statistics are derived from mandatory reporting requirements for bull permit holders whether the hunter was successful or not; harvest reporting for antlerless animals is voluntary. Originally, harvest reports were obtained by mail-in forms, but this has been replaced by on-line or toll-free telephone reporting procedures. Field personnel periodically collect additional information and/or samples, including antler measurements, incisor teeth for age determination by counts of cementum annulations, and recently tissues to test for the possible presence of chronic wasting disease.

POPULATION HISTORY, PRODUCTIVITY, AND HARVEST

Counts fluctuated from 57-90 animals in 1957-1967, but accelerated dramatically thereafter, increasing to >300 animals by 1971. Subsequently, the state population has continued to increase, with resident herds becoming established on the South Slope of the Uintas and along the north-south axis of the Wasatch Mountains (Fig. 1). Moose expansion into these areas was characterized by increased occupancy of non-riparian areas, namely more xeric habitats dominated by shrubs or trees. These pioneered habitats include a variety of vegetation types such as mountain mahogany (*Cercocarpus sp.*), serviceberry (*Amelanchier alnifolia*), Gambel oak (*Quercus gambelli*), and higher elevation conifer stands (e.g., *Pinus contorta, Picea engelmannii*). The population increase of the Uinta herd and expansion into other areas generally coincides with above-average precipitation during the 1970s into the mid-1980s.

The finite rate of increase (λ) of the estimated statewide population averaged 1.12 in1957-1991 (Fig. 2). Concerns about an apparent increase in winter mortality prompted substantial increases in harvest during the early 1990s. This was especially true of the annual antlerless harvest that increased more than sevenfold to an average of 87 animals in 1990-1993, in contrast to only 12 animals the preceding decade. This spike in antlerless harvest was likely responsible for the dip in population size (Fig. 2). Beginning in 1997 the population trajectory resumed an upward

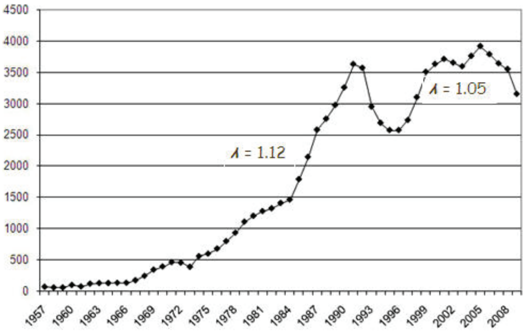

Fig. 2. Estimated trend of the Utah moose population, 1957-2008.

trend, albeit at a lower rate (λ = 1.05). The most recent (2005-2009) decline is associated with the translocation of ≥100 animals (predominately cows and calves) to Colorado and increased antlerless harvest levels. Estimated densities for individual management units in 2009 ranged from approximately 1 to as high as 50 (mean = 10.7) moose/100 km^2. The highest densities occurred in the Northern Region, notably Units 3 and 5, with densities of 37.2 and 49.9, respectively; these units adjoin the populous Wasatch Front (Table 1).

Long-term mean productivity (calves/100 cows) for all units was 53.2 (S.E. = 11.9), ranging from 41.5 to 70.8 on the Wasatch Mountains and Cache units, respectively (Fig. 3). Some evidence suggests that productivity may have declined over time in the northern part of the state. This is manifested in negative temporal trends in calf:cow ratios on several management units. Whether these trends represent the effects of density dependence or environmental conditions is unclear. We regressed calf:cow ratios as a function of both time and the total number of animals counted in aerial surveys. This analysis was constrained in 2 ways: 1) only units with ≥10 years of data were included, and 2) counts with <50 animals were excluded. Because of the nature of the data, we used a critical probability of $p \leq 0.10$. All comparisons revealed apparent negative relationships, but only 3 units (Chalk Creek, Morgan-Rich, and the North Slope) showed significant declines over time (Table 2). Moreover, only the Chalk Creek unit showed a significant negative relationship with population size.

In 1958-2008, a total of 6,119 (4,942 bulls and 1,177 antlerless) moose were legally harvested by 6,685 hunters with an overall mean hunter success rate of 92%. Harvest age data was available from 1986-2008; harvested bulls averaged 5.0 years with a low of 4.1 in 1988 and a high of 5.5 in 2006.

Translocations

Historically, attempts to transplant moose have occurred in several locations throughout North America (Pimlott and Carberry 1958), and on at least 2 occasions moose were moved from North America to New Zealand (Wodzicki 1950). These efforts involved winter trapping and surface transport of the

Table 1. Size, population estimate, and estimated density of moose (moose/100 km^2) in Herd Units in Utah, 2009. Numbers in parentheses refer to those in Fig. 1.

Unit	Area (km^2)	Population estimate (2009)	Density (moose/ 100 km^2)
Cache (2)	2,448	200	8.2
Ogden (3)	1,303	485	37.2
Morgan-South Rich (4)	2,326	475	20.4
East Canyon (5)	701	350	49.9
Chalk Creek (6)	1,557	550	35.3
Kamas (7)	622	65	10.5
North Slope (8)	2,469	375	15.2
South Slope (9)	4,694	210	4.8
Nine Mile, Range Creek (11)	741	15	2
Central Mountains, Manti (16)	5,958	25	4.1
Wasatch Mountains (17)	5,447	410	7.5
Plateau, Fish Lake (25)	1,389	15	1.1
Total Suitable Habitat	29,656	3,175	10.7

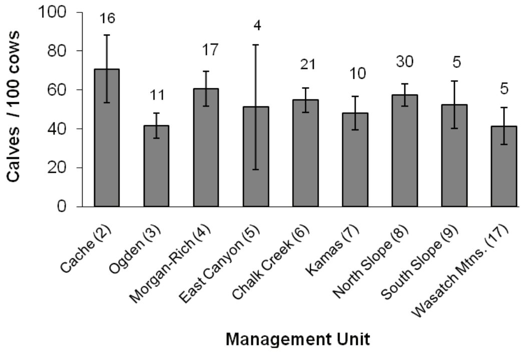

Fig. 3. Comparative long-term productivity (calves/100 cows) of 9 northern Utah moose herds. Error bars represent ± 1 SE of respective point estimates. Numbers above bars indicate number of years of data.

animals. Wyoming attempted 3 intrastate moose transplants between 1934 and 1950 (Grasse 1950). Utah was the first state agency to employ helicopters in the capture of animals for translocation. Early efforts beginning in 1973 involved chemical immobilization with drugs delivered from dart guns, but starting in 1993 captures were accomplished by means of net-gunning.

Since 1973, a total of 345 animals have been translocated within the state with an additional 115 animals moved to Colorado. The primary goal of these efforts was to augment existing populations or establish new populations in potential moose habitat. More recently, an ancillary objective has been the removal of excess animals from peri-urban areas. These efforts have resulted in limited success, with those animals moved to the central, southern, and eastern portions of the state generally failing to achieve viability.

As an example, 99 animals were translocated to the Fishlake National Forest in 1988-1992. National Forest Service records of sightings by recreationists indicated a continuous, albeit declining presence of moose on the Forest and limited reproduction. In 1988-1992 there were 30 confirmed mortalities on the Fishlake National Forest. Although cause of mortality was undetermined for 20 animals, illegal kill (6), highway mortality (2), and cougar predation (2) accounted for the rest. In winter 2009 only a single cow and calf were observed during the course of aerial surveys for elk conducted by Utah Division of Wildlife Resources (UDWR) biologists on Fishlake National Forest. Similarly, 112 moose were translocated to the Hill Creek Extension of the Uintah and Ouray Indian Reservation in the Book Cliffs of eastern Utah. However, those animals largely disappeared from Tribal lands and as of 2000 only an estimated 10 animals remained in the area (K. Corts, Ute-Ouray Indian Nation, pers. comm.).

Moose have fared generally better in the central areas of the state. A total of 99 animals were translocated to the Central Mountains Unit of the Manti National Forest in 1973-1996. Total moose counted during elk surveys conducted in1998-2007 varied from 3-15 animals, with the highest count occurring in 2004 (B. Crompton, UDWR, pers. comm.). An average of 70-80 h of helicopter time are spent surveying the unit.

No moose have been transplanted to the Nine Mile Unit (11), but animals have pioneered into the area. Incidental summer observations (2008) and aerial surveys (2009) confirmed the presence of at least 9 animals. The Wasatch Mountains population has shown an upward trend, with the population nearly doubling from 1999-2008.

Table 2. Regression analyses of productivity indices (calves/100 cows) as a function of time and population size. In units with ≥10 years of data, counts with <50 animals were excluded.

Unit	n (yrs)	Calf-cow vs. time		Calf-cow vs. population size	
		R	*P*	*r*	*p*
Cache	11	-0.397	0.226	-0.213	0.530
Chalk Creek	16	-0.647	0.007	-0.640	0.008
Morgan-Rich	10	-0.546	0.103	-0.194	0.591
North Slope	29	-0.470	0.010	-0.294	0.122
Ogden	11	-0.444	0.172	-0.204	0.547

The disparate performance of translocated animals poses the question as to the possible causal mechanisms involved. Evidence suggests that a combination of contributing factors are likely responsible, including illegal kill, highway mortality, and predation. However, the possible role of differential habitat suitability cannot be discounted. *Prima facie* it appears that transplants south of approximate latitude of 40° N have not prospered. Various authors, notably Kelsall and Telfer (1974), have postulated that extreme summer temperatures may limit the southern distribution of moose. We compared mean maximum daily summer (June-August) temperatures from 24 and 14 Snotel stations in the northern and southern portions of actual and potential moose range in Utah, respectively. Mean elevations for these samples were 2,688 m and 2,678 m, respectively, with mean daily maximum temperatures of 20.2° C and 21.1° C, respectively. The modest differential in temperatures suggests that this factor alone may not account for the observed disparity in population performance.

Availability of free water for drinking and passive thermoregulation may serve to ameliorate the negative impacts of temperature. Direct quantification of possible differences in this variable is difficult and consequently we employed a GIS approach. We developed a composite GIS water layer from the Utah Automated Geographic Reference Center which aggregated lakes, streams, and springs. Subsequently, the mean distance to water was calculated for all points within actual and potential moose habitat by unit and subunit. As shown in Fig. 4, these analyses indicated generally lower mean distance to water for the northern units as opposed to southern units, with the exceptions of the East Canyon (5) and Fishlake Units (25). However, these differences were not significant.

Moose populations in Utah are contiguous with those in southern Wyoming and Idaho, but Colorado is relatively isolated and historically moose were considered incidental in that state (Bailey 1944). Utah moose served as one source of animals in efforts to establish resident moose populations in northwestern and southwestern Colorado beginning in 1978 and continuing as recently as 2005-2007. The incipient herds, augmented by intrastate transplants and additional animals from Wyoming, have increased to viable populations comprising a statewide total of >1,000 animals on 3-4 areas in various parts of western Colorado. Several authors (e.g., Duvall and Schoonveld 1988, Olterman et al. 1994) have described the relative success of these transplant efforts. Kufeld and Bowden (1996a, b) have reported on the survival, movements, and habitat selection of the herd in northcentral Colorado. A detailed assessment of the performance of these populations is beyond the scope of this paper, but a few points of similarity merit mention. Two of the Colorado populations occur at latitudes comparable to that of the Fishlake transplant attempts in Utah. Apart from sport harvest, illegal kill was a leading cause of mortality. Kufeld and Bowden (1996*b*) noted the importance of plant communities comprising a mix of riparian/willow, seral aspen (*Populus tremuloides*), and climax coniferous forests stands.

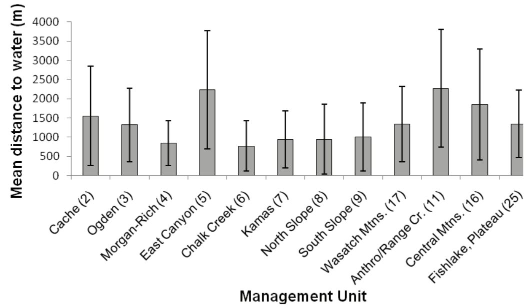

Fig. 4. Mean (± SD) distance to water (m) by moose management unit in Utah. Management units 11, 16, and 25 are south of the 40° N parallel.

Research

Utah's moose population has been the subject of several interesting research efforts, most of which have featured the Uinta North

Slope management unit. Perhaps the most noteworthy was Wilson's (1971) attempt to estimate the winter carrying capacity of the then burgeoning North Slope herd. Based on existing literature, he estimated the daily food requirement of an average adult moose. He also estimated empirically the caloric capacity of the current annual growth (CAG) of the 2 principal winter browse species, namely Drummond's and Geyer's willows (*Salix drummondiana* and *S. geyeriana*) that accounted for 59 and 31% of the available winter browse and 92.0 and 4.7% of all recorded winter feeding occurrences, respectively. From those data, Wilson computed the winter carrying capacity of the key winter browse species to be 80,000 moose days or an equivalent of 445 adult animals for a winter occupancy period of 6 months.

Subsequently, Babcock (1977) attempted to refine this estimate. He evaluated the effects of 3 simulated levels of moose browsing on nutrient content, digestibility, and vigor of willow plants. Additionally, he compared the nutritional parameters of CAG with previous years' growth (2-5 year old twigs). Clipping caused a significant increase in crude protein and phosphorus content among treatment levels simulating 0, 30, 60, and 90% removals. Digestibility varied significantly among years, but was consistently lower (16-36%) than the 50% value used in Wilson's computations. Plant vigor comparisons were confounded by additional sources of mortality and the influence of different precipitation levels between years. Babcock concluded that decreases in estimated carrying capacity related to changes in these variables were partially compensated by refined estimates of the areal extent of the winter range.

In a parallel study on the North Slope, Babcock et al. (1982) evaluated both empirically and via population projection techniques different management alternatives, namely maximum yield versus trophy management. Manipulation of the adult sex ratio by sex-discriminate harvests produced changes in herd productivity. During the period 1964-1971, the mean bull:cow ratio observed in winter counts was 1:2.2 and the mean productivity was estimated at 74 calves/100 cows. Following artificial adjustment (1974-1977) of the bull:cow ratio to approximately 1:3.6, the mean productivity was estimated at 46 calves/100 cows. Returning the bull:cow ratio to pre-treatment levels (1.0:2.1) during the period 1979-1981 resulted in an apparent increase in productivity (59 calves/100 cows). Whether those results were influenced by the herd approaching its estimated carrying capacity remains unknown.

Hunter concerns about a possible decline in the abundance of large-antlered bulls prompted a comparison of antler measurements (width and number of points) using data collected from hunter-harvested moose from 1972-1979 (Babcock et al. 1982) with antler measurements collected in 2004-2008. Neither the raw data nor variance estimates were available for the 1972-1979 data thus precluding statistical analysis, however mean antler width by age class for the 2 time periods was comparable (Table 3). The only noticeable difference in the point estimates for antler spread occurred in the 6.5 and 7.5 year age classes; however, given the overlap in the data ranges, it is unlikely that there is a statistical difference. Similarly, antler point data shows no detectable difference between the 2 time periods. Thus, although many hunters feel that antler quality has decreased over time, long-term data suggest it has remained relatively constant.

LIMITING FACTORS

Perhaps the best approach to evaluate the future of moose in Utah is to examine the potential limiting factors. With the exception of disease, most of these have been identified in the discussion of the relative success of transplant efforts. Illegal kill, highway mortality, and predation probably do not pose major

Table 3. Comparison of age and age-specific antler measurements (cm) for Shiras moose harvested on the Uinta Mountains North Slope Unit, Utah, 1972-1979 and 2004-2008.

	1972-1979			2004-2008		
Age	n	Greatest Spread	Antler points	n	Greatest Spread	Antler points
1.5	40	63	3-3	1	68.6	1-2
		(39.4–86.4)	(Spike–6)		(—)	(—)
2.5	47	71.1	4-5	2	73.7	4-4
		(46.4–97.8)	(Spike–10)		(71.1–76.2)	(3–4)
0.5	70	84.8	6-6	12	88.1	5-5
		(50.8–121.9)	(Spike–13)		(61.0–101.6)	(Spike–9)
4.5	34	102.4	7-7	18	95.8	7-7
		(81.3–132.1)	(3–11)		(76.2–114.3)	(3–10)
5.5	10	106.7	7-7	15	106.8	8-8
		(95.0–114.3)	(3–11)		(86.4–121.9)	(2–13)
6.5	12	112.3	8-8	12	105.9	7-7
		(96.5–130.2)	(3–11)		(86.4–121.9)	(3–10)
7.5	8	120.4	9-9	6	104.1	8-8
		(104.1–143.2)	(4–13)		(73.7–127.0)	(4–11)
8.5	1	96.5	8-8	8	99.4	8-7
		(—)	(—)		(86.4–111.8)	(5–12)
9.5	1	120.6	9-9	7	102.1	5-6
		(—)	(—)		(58.4–120.0)	(Spike–10)
10.5	1	116.8	9-9	5	106.7	6-6
		(—)	(—)		(99.1–116.8)	(3–10)
11.5	—	—	—	1	121.9	14-8
					(—)	(—)
12.5	—	—	—	1	128.9	8-7
					(—)	(—)

threats on a statewide basis, but cumulatively may affect the persistence of newly translocated populations.

Predation and Illegal Kill

Wolves (*Canis lupus*) are one of the primary predators of moose over much of their holarctic distribution, and although several transient wolves have passed though the state since 2002, they have yet to reestablish in Utah. Cougars and black bears (*Ursus americanus*) constitute the only 2 potential moose predators in Utah; the first appears to be more problematic. Although black bears may kill substantial numbers of neonatal moose calves in some locations (cf. Ballard and Van Ballenberghe 1998), this appears to be infrequent in Utah. Bear densities are highest mostly in southern and eastern regions where moose are largely absent, thereby limiting the potential for predatory interaction. Heward et al. (2004) examined black bear diets from 3 locations in Utah, one of which (Hobble Creek, Management Unit 16) was inhabited by moose; scat analyses (n = 179) indicated no evidence of moose remains.

Cougar predation on moose has been documented by several investigators, and in some locations moose may comprise 7-15% of the diet (Ross and Jalkotzky 1996, Knopff et al. 2009). Available evidence suggests that the bulk of this predation is directed toward calves and yearlings, and that individual male cougars may specialize on moose when present in sufficient numbers. In Utah, 4 (57.1%) of 7 radio-collared moose were killed by cougars among 26 animals transplanted to the Manti National Forest in 1996. Similarly, cougar kills were 2 of 9 known fatalities among moose transplanted to the Fishlake Plateau.

Illegal kill of moose has been a recurring problem in Utah. Numerous animals have been killed either intentionally or incidentally during hunting seasons for deer (*Odocoileus spp.)* and elk. This problem was particularly prevalent on some of the northern units in the 1970s-1980s. However, the frequency of moose kills due to misidentification has decreased as the result of an extensive public education program and signage. This notwithstanding, poaching may have been the principal factor contributing to the failure of the original moose transplant to the Manti during the 1970s. During the subsequent period of several years, more animals were killed illegally than were released on the unit.

Highway Mortality

Vehicular collisions with moose constitute a perennial but variable-level problem in Utah. Incidence of collisions is associated with 3 principal factors: 1) highway type, 2) winter severity, and 3) moose density. Most of the documented road-killed moose occur along several segments of interstate highways I-80 and I-84, as well as U.S. Highways 6, 40, and 89, and State Road 39 (Fig. 1) Not surprisingly, the 2 interstate highways pass through those units with the highest moose densities, namely Units 3, 5, and 6 (Table 1).

Consistent tallies of moose killed on highways have only been maintained relatively recently. In the Central Region, during the period October 2004-February 2010, a total of 90 animals were collected by a contractor for the Utah Department of Transportation. Of these fatalities, 53.3% and 34.4% occurred on 2 major highways east of Salt Lake City, specifically I-80 and U.S. 40 (Fig. 1). Although cows predominated in the overall sample (34 female:24 male), the observed difference was not significant and was reasonable given the bull:cow ratio for this unit. For the 5 years (2005-2009) for which complete annual counts exist, the mean number of animals killed annually was 16.4 (range = 15-19). In terms of actual mortality, these statistics are likely conservative and do not include animals dying outside of the highway right-of-way, nor do they include a comparable estimate from highways in the Northern Region.

Pathogens

At this time the 2 high-profile diseases of moose do not appear to pose a significant threat in Utah. Specifically, Paraelaphostrongylosus or moose neurologic disease is not a concern, because the causative parasite has not been found in the non-pathogenic host, white-tailed deer (*O. virginianus*) in the western United States, and habitat overlap between moose and white-tailed deer in Utah is minimal. Chronic wasting disease (CWD), a contagious, slow-acting, and fatal degenerative disease caused by prions is known to affect various cervids including moose (Miller et al. 2000). This disease was first documented in free-ranging moose in 2005 near Jackson County, Colorado (Baeton et al. 2007). In Utah CWD was first documented in mule deer (*O. hemionus*) in 2002 and occurs in 3 distinct geographic areas, the Central Mountains, the North and South Slope management units, and the La Sal Mountains unit in southeastern Utah, (L. McFarlane, UDWR, pers. comm.). Of those units the North Slope is the only location where substantial numbers of moose occur, and the prevalence rate for CWD in mule deer in this area is <1%. Currently all symptomatic and clinically ill moose are tested for CWD and this disease has not been detected in Utah.

Perhaps the most significant parasite of

Utah moose is the arterial worm (*Elaephora schneideri*). This is a parasite of the carotid and maxillary arteries of mule deer, which likely serve as a reservoir (Hibler and Metzger 1974), as well as other wild and domestic ungulates. Most if not all Utah moose populations share ranges with mule deer. Although non-pathogenic in mule deer, *E. schneideri* has detrimental effects on elk (Radeke et al. 2002) and moose (Madden et al. 1991). Tabanid species serve as vectors for the parasite. Clinical signs include cropping of the ears, necrosis of the muzzle, brain damage, locomotive abnormalities, and a condition known as clear-eyed blindness. *Eleaophorosis* has been identified as the cause of death in 17 moose from northern management units (L. McFarlane, personal communication). The disease has been suggested as a possible factor contributing to the failure of the Fishlake transplant.

Contact with domestic livestock may facilitate transmission of other diseases infecting moose. Moose appear to be particularly susceptible to infectious keratoconjunctivitis (IKC) or "pinkeye." This is a bacterial infection (*Moraxella* spp.) that causes corneal opacity and ulceration in many wild and domestic ungulates. The IKC bacterium is commonly associated with cattle and transmission usually occurs from close contact with infected animals. In general, 5-10 moose in northern Utah are reported annually with this condition. Although sporadic and occasional, these outbreaks may have population implications in some areas.

Malignant catarrhal fever (MCF) is a highly infectious form of the gamma-herpes virus with numerous clinical symptoms and is often fatal. Research has suggested that MCF in moose is highly lethal (Li et al. 1996, Vikoren et al. 2006). Domestic sheep and goats are often asymptomatic carriers of this disease, and many Utah moose share summer and winter range with domestic sheep. MCF is suspected in the deaths of several moose in northern Utah with clinical symptoms similar to those found in infected domestic animals, including diarrhea, bloody stools, nasal mucous discharge, opaque colored eyes, dropped head, and lethargy. Presence of the virus could not be confirmed in these animals, most likely due to sample degeneration or contamination (L. McFarlane, pers. comm.).

White muscle disease is caused by vitamin E or selenium deficiency and may be induced by poor winter nutrition. Affected animals usually exhibit lameness, excessive salivation, and sudden death from heart degeneration (Blowey and Weaver 2003). Since 2003 toxicology surveys conducted on translocated moose have identified 15 animals with this condition, most of which stemmed from selenium deficiencies. These animals were found in late-winter and spring and the occurrences may be related to habitat and winter range conditions (L. McFarlane, pers. comm.).

Utah moose are also affected by ectoparasites, notably winter ticks (*Dermocentor albipictus*). As in other locations, infestation rates vary annually. For example, during the relatively severe winter of 2007-2008, several of the mortalities found in the Northern Region harbored unusually heavy loads of ticks (A. Wing, UDWR, pers. comm.). Although tick infestations do not cause disease directly, pathological effects include removal of blood by feeding ticks and the consequences of grooming as the result of irritation. These include hair loss and the disruption of normal feeding behavior (Mooring and Samuel 1999), which in extreme cases could lead to emaciation and thermoregulatory problems. DelGiudice et al. (1997) suggested a positive relationship between April weather (warm temperatures, low precipitation, and absence of snow cover) and survival of female winter ticks after leaving their ungulate host and before laying eggs. Thus, early spring weather may be a significant factor determining the proportion of female ticks that survive to lay eggs, hence, the number of larvae that hatch and seek ungulate hosts in the fall and ultimately the severity of infestation the following winter.

Interspecific Competition and Habitat

The consequences of competition between moose and elk are often discounted because of assumed resource partitioning between the species (Boer 1998, Miller 2002). This is based on the premise that moose and elk are principally browsers and grazers, respectively, and tend to occupy different habitats, i.e., riparian versus upland, respectively. The fact that this is not universally true for moose in Utah was noted earlier. Moreover, Miller (2002) conceded the possibility of significant competition in situations where elk numbers are allowed to increase unchecked. The abundance of elk in Utah has increased approximately 11-fold since the 1960s with a current estimated statewide population of >63,000 animals (Hersey and Aoude 2006). More importantly ~30% of this total occurs in the southern and eastern parts of the state, thus substantially overlapping areas where attempts to establish new moose populations have met with limited success. Formal studies of moose-elk interactions have not been undertaken in Utah. However, elk are potentially superior competitors from several standpoints, including a broader feeding spectrum by virtue of a larger rumen:body size ratio (Hofmann and Steward 1972). They are also quite tolerant of extreme summer temperatures as evidenced by populations in eastern Washington (Rickard et al. 1977). As demonstrated by Cook et al. (1998), thermal cover for elk may not be as important as previously supposed.

Virtually all moose management units in the state comprise a significant fraction of public lands and thus are subject to summer grazing by domestic cattle and sheep, both of which may negatively impact riparian areas. The definitive work on competition between moose and cattle remains that of Dorn (1970), who investigated food habits of the 2 species on the Red Rock Lakes Wildlife Refuge in southwestern Montana. He considered forage competition to be insignificant because of minimal dietary overlap between the 2 species, but conceded the possibility of greater competition in situations with high stocking rates.

FUTURE PERSPECTIVES

Although a recent arrival to Utah, moose are well established in the northern half of the state, due in part to effective management practices. As noted previously, moose appear to have prospered in some upland shrub-dominated communities. Average densities and indices of productivity in northern herds are comparable to or moderately higher than those reported in neighboring states, specifically Idaho (Toweill and Vecillio 2004) and Wyoming (Brimeyer and Thomas 2004). However, efforts to establish viable populations in the southern portion of the state have met with only modest success. This review has not identified any single and potentially universal limiting factor determining the relative success of individual populations.

Habitat, possibly linked with climate change, appears to be the principal determinant of moose distribution and abundance in Utah and possibly other areas of the Rocky Mountain West. Moose habitat is affected by a plethora of factors, both natural and anthropogenic, only a few of which are discussed in this context. In parts of the western United States moose habitat frequently interfaces with expanding urban areas, sometime necessitating removal or relocation of "nuisance" animals. Currently, most of these situations involve younger animals and occur in high-density units along the Wasatch Front, generally during spring and summer.

Geist (1971) distinguished between permanent and transient moose habitat, the latter typically comprising early successional or subclimax plant communities resulting from natural (fire) or human (logging) perturbation of coniferous forest stands. In this context 2 factors deserve mention. The first is the increasing severity and areal extent of insect epidemics, notably by bark beetles (*Dendroctonus spp.*) in stands of lodgepole pine (*Pinus contorta*), Douglas fir (*Pseudotsuga menziesii*), and Engelmann spruce (*Picea engelmannii*). The potential effects of these pathogens on moose habitat are two-fold and possibly counteracting, namely: 1) increased production of early successional forage (Wolfe 1974), and 2) loss of thermal cover. As an example of the former effect, Stone (1995) observed a linear (r = 0.84) increase in the number of moose fecal pellets associated with increasing (0-90%) tree mortality in post-epidemic stands of lodgepole pine on the Uinta North Slope.

A regional decline in aspen in the western United States constitutes the other factor potentially impacting moose habitat in Utah. The causal mechanisms involved are complex and remain inadequately investigated, but have been attributed to a combination of successional processes in which fire suppression and long-term overgrazing by ungulates figure prominently (Bartos and Campbell 1998). Existing conditions indicate that most aspen stands will eventually be replaced by conifers, sagebrush (*Atemisia tridentata*), or possibly other shrub communities.

The direct and indirect effects of climate change on moose and habitat in Utah are largely unknown. Earlier investigators postulated that summer temperatures ultimately might constrain the southerly distribution of moose (Kelsall and Telfer 1974, Rennecker and Hudson 1986). More recently, Murray et al. (2006) and Lenarz et al. (2009) implicated heat stress, acting in concert with pathogens and poor nutrition, as causal mechanisms for declines of moose populations in northwestern and northeastern Minnesota, respectively. Lenarz et al. (2009) predicted that continuation or acceleration of current climate trends will result in decreased survival and density and ultimately a northward contraction of moose range. Given the possibilities of increasing aridity, a similar suite of factors could impact the species in Utah.

Another factor which has received little attention is the degree of habitat modification in the wake of epidemics of forest pathogens. For example, as postulated by Logan and Powell (2000), warmer average temperatures would allow mountain pine beetles to complete their life cycle in a single season, thereby explaining recent increases in the areal extent and severity of beetle-caused mortality in lodgepole pine in several areas of western North America. Lodgepole pine has been reported as winter forage for moose by several authors (e.g., Harry 1957, Houston 1968, Ritchie 1978), and comparable scenarios might exist for other pathogens of coniferous forests. More importantly the value of lodgepole pine and other coniferous forest types may lie in their value as hiding and thermal cover (Schwab and Pitt 1991).

Utah's status as the second-most arid state in the conterminous U.S., and its position on the southern periphery of *Alces'* Nearctic distribution may have implications for the future of the species in western North America. It appears that the establishment of moose in Utah and the species' expansion into adjacent areas, including pioneering into upland habitats, occurred during a period of above average precipitation. Several of the northern populations currently appear to have reached either biological or sociological carrying capacities. Efforts to establish new populations into suitable habitats in the southern portion of the state have met with only partial success. For the future, climate change, acting either directly or in concert with other factors may constrain the viability of moose populations in the state.

Our attempts to use climatic variables to compare the relative performance of herds in northern and southern portions of the state was probably overly simplistic, given that thermoregulation is likely a product of several variables including airflow and thermal cover afforded by vegetation (Rennecker 1990). Accordingly, a more sophisticated analysis that incorporates these and other parameters is warranted to better define what constitutes suitable moose habitat. One possibility would be to explore the use of normalized difference vegetation indices (NDVI) as comparators among different management units. These satellite-based measurements correlate well with aboveground net primary productivity (Pettorelli et al. 2007). We also suggest that investigations of this nature might be well-advised prior to future translocation attempts of moose to southern locations of Utah.

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