TECHNIQUES OF MOOSE HUSBANDRY IN NORTH AMERICA

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ABSTRACT: Moose (*Alces alces*) are maintained in captive or semi-captive conditions in North America for display and education, scientific research, and commercial breeding. Moose husbandry techniques are widely scattered and in most cases poorly documented. In this review, I summarize husbandry techniques obtained from a survey of most facilities in North America with moose. In addition I summarize our experiences from the Moose Research Center where a large number (15 - 32) of moose are kept. Detailed descriptions of physical facilities, techniques for feeding and care of adults and calves, and maintenance of herd health are presented and discussed. Minimum facilities require at least a 2.13 m woven wire fence and shelter. With adequate shelter, moose can tolerate extreme cold and wind, but warm temperatures impose stress; shade and cooling ponds or sprinklers are important. A formulated ration meeting nutritional and physical requirement of moose has simplified feeding and reduced labor costs. Most moose are supplemented with fresh cut browse and other green plant material. Disease, particularly in calves, can result in high mortality. Moose do not survive in captivity as long as they do in the wild.

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Speidel (1965:88) in his review on the care and nutrition of moose stated that, "Paradoxically this largest and most powerful member of the deer family is difficult to keep in captivity and this poses a challenge to any zoo." Such was the case when we began working with captive moose at the Moose Research Center (MRC) in 1977. Research being conducted at the MRC required a herd of tractable moose maintained under captive conditions. A review of the literature and correspondence with zoos and other research facilities revealed that keeping moose under captive conditions was difficult (Schwartz *et al.* 1980). A major obstacle at the time was a lack of a suitable ration. Unless moose were fed browse, they inevitably died of chronic wasting resulting from diarrhea.

Within the past decade, our understanding of the nutritional and environmental requirements of moose has flourished (Franzmann *et al.* 1987, Hjeljord 1987, Schwartz *et al.* 1987a). A small number of moose are now maintained throughout North America under a variety of captive and semi-captive conditions. The intent of this paper is to review current husbandry techniques used in North America.

METHODS

I used 3 methods to locate facilities in North America that kept moose in captivity. First, I contacted all the major zoos listed in the National Zoo Directory for North America. Second, I requested a list of facilities keeping *Alces alces* listed with the International Species Information System. And third, I contacted moose specialists in all jurisdictions of the United States and Canada where moose occur. I requested the names and addresses of zoos, wildlife parks, game ranches, and research facilities that kept moose. Each facility contacted was asked if they kept moose and, if so, to cooperate in a husbandry survey.

RESULTS

I contacted 121 different zoos, research facilities, and game farms, of which 100 responded. With the exception of a few game farms in Alberta, most of the 21 non-respondents were zoos located in parts of North America well outside the geographic range of moose. I did not send a follow-up letter. Of the 100 facilities that did respond, 29 kept moose and all agreed to participate in the survey. I mailed a second questionnaire to all

29 facilities with moose. Twenty-six completed the questionnaire, 2 did not respond, and at 1 facility the owner did not speak English and was unable to participate. I sent follow-up letters to the two non-respondents, but Bear Country USA, and Wildlife Safari chose not to participate.

There was considerable variation in the detail with which each respondent answered each question. For this reason, sample sizes varied among questions and responses. Also, there was variation in experience and the duration that the 26 facilities kept moose. The longest history spanned 52 years, and the shortest only 1 year. Nine facilities kept moose >20 years, 10 10-20 years, and 7 <10 years.

The primary reasons for keeping moose were display and education (n = 14), wildlife research (n = 9), and breeding on game farms (n = 3). In addition to display, 3 facilities raised orphaned calves as a service to their local Wildlife Department. No respondent indicated they raised moose for meat production.

Thirteen facilities listed *A. a. andersoni*, 10 *A. a. americana*, 5 *A. a. gigas*, and 1 *A. a. shirasi* as the subspecies of moose kept; 4 listed more than one subspecies. All but one facility obtained their original stock from the wild, usually within the state or province where the facility was located. Only 2 facilities (6%) have kept moose for 5 generations; most have kept moose for only 1 (35%) or 2 (30%) generations. Most facilities routinely supplemented their captive stock with animals from the wild.

Nine facilities provided sale prices of moose and 2 listed purchase prices. Prices for bulls averaged $1,500 (all prices are in 1990 US dollars), and ranged from $1,000 to $5,000. Females older than calves averaged $3,500, with the low price listed at $1,500: the top price listed was $6,500. Calf prices were the most variable, ranging from $7,000 (this person did not provide sale values for cows and bulls) down to $1,200. One person providing separate prices for male and female calves. The average sale price listed for a calf was $500-1000 less than that for a cow.

Physical Facilities

Fences—There was much diversity in the size and make-up of the physical facilities used to keep moose. Fencing used was either chain link (35%) or woven wire (65%). The most common type of woven wire was 5 X 10 cm or 15 X 15 cm squares in 12 or 9 gauge wire. No facility used electric fence.

Fence height ranged from 1.8-3.1 m but 2.1-2.4 m fences (92%) were by far the most common. The facilities with a 1.8 m fence indicated they had moose jump out. Three facilities located in areas with naturally occurring wild moose and deer (*Odocoileus spp*) indicated that they occasionally have wild moose or deer jump into their pens. Two had 2.1 m fences, and 1 had a 2.4 m fence. One facility eliminated moose jumping in by putting a top rail around their holding pen.

Post spacing ranged from 2.4 m to 7.3 m, but most were 3-5 m apart. Galvanized metal or 10 X 10 cm treated wood posts was the most common type listed. Only 5 (20%) facilities used a top rail. A few facilities indicated that they had guard rails parallel to the ground at varying heights (0.6-1.8 m) above the ground.

Most respondents liked their fences. One facility indicated that on 2 occasions they had young calves get tangled in the 15 X 15 cm woven wire mesh when they became frightened and ran into the wire. A few individuals indicated the lighter gauges of wire were easily damaged by the antlers of bulls. We have had similar experience at the MRC. One facility indicated that they have had animals chew on wooden posts and other furnishings within the pen. They felt that this was a result of a lack of adequate browse. Two facilities had occasional problems with black bears (*Ursus americanus*) and wolves (*Canis lupus*) digging under their fences.

There were several suggestions given to improve fencing design. Probably the most common was to put the fence wire on the inside of the posts. This provided a smooth fence line within the pen, and prevented bulls from "popping fencing staples" when they pushed on the wire. One facility attached an apron of fencing 91 cm wide which was buried. This apron effectively kept wild predators and dogs from digging into the pen. One respondent felt sliding gates facilitated easy animal handling.

At the MRC, we tested the New Zealand type electric fencing (Gallagher-Snell Power Fence, San Antonio, Texas) which is high voltage (7,900 V). The fencing worked and successfully confined moose, but required much maintenance, particularly when we kept antlered bulls in the pens. From our observations, it appeared that hardened antlers did not always conduct electricity. We watched bulls touch the electric wires with their antlers and show no indication of a shock. As a consequence, one male pulled down part of the fence wire. Animals touching the fence with long winter guard hairs occasionally received no shock. Snow acted as an insulator, therefore positive and negative wires were alternated on the fence to assure adequate grounding of animals touching the fence.

Shelter—Moose are well adapted to the northern environment and with adequate protection from wind they can tolerate very cold temperatures (-30 C) (Renecker and Hudson 1986). Fourteen (64%) of the facilities provided their moose with a winter shelter. Barns, block houses, or 3-sided shelters were the most common. No facility used a heated shelter. Eight (36%) provided no shelter but the holding pen contained dense stands of coniferous trees. No respondent indicated winter weather caused their animals problems. One facility used their shelter as a holding and switching area.

Although moose are capable of maintaining body temperatures in extremely cold weather, they stress easliy in heat and humidity. During the summer, moose begin to show signs of heat stress when temperatures exceed 14-20 C (Renecker and Hudson 1986). Cooling facilities (n = 24) included shelters (38%), ponds or streams (50%), trees (50%), and sprinklers and misters (17%). Most (71%) had more than one type of cooling facility. Facilities located south of normal moose range used sprinklers. Most people indicated those moose seek cool places, particularly water, when temperatures reach 27 C and/or humidity is high. No facility indicated heat stress to be a major problem.

Several people provided valuable suggestions to improve holding facilities. In smaller enclosures, protection of trees from overbrowsing and physical damage was important. Bulls need a few unprotected trees and shrubs to rub velvet from antlers.

A hard concrete surface near the feeding area was useful to prevent muddy conditions from developing in this high use area. Concrete also provided a rough hard surface that ensured adequate hoof wear. Several people who kept moose on soft substrates indicated hoof growth problems. Conversely, one facility indicated excessive hoof wear due to a concrete floor in their shelter; the moose liked this shelter and spent a considerable amount of time in it.

Stocking rates—Stocking rates varied among facilities, with as few as 1 moose/60 ha when moose were consuming natural forages to as many as 1 moose/0.1 ha when they were on display and fed a formulated diet. When moose were stocked at a high density, the facilities in all cases kept fewer than 3 moose but even then most facilities maintained a density of about 1 moose/0.5 ha. At the MRC, we have maintained a mixture of cows, calves, and bulls in groups ranging from 5-15 individuals in a 4 ha pen during fall and winter. The pen contains several areas of dense spruce cover allowing animals to segregate. With this number of animals, we did witness aggression, especially in the area where the animals were fed the pelleted ration.

All but 2 facilities kept bulls mixed with cows. The two not keeping males reared only females and one of these facilities imported a bull for breeding. One facility kept bulls separated from females from calving to breeding season. Four research facilities removed the antlers from males: no facility displaying moose removed antlers. One zoo also removed antlers from animals that were shipped. Rutting males can cause problems including destruction of fences, feeders, and trees. Several people cautioned about the dangerous nature of male moose during the rutting season. Only one facility indicated that an antlered male had injured a female. A 3-year-old bull gored a yearling female at the MRC. This female died from the injuries.

Feeding and Care

Calf Raising—Several references in the literature address bottle-raising of neonatal moose calves (Addison and Dodds 1959, Yazan and Knorre 1964, Markgren 1966, Regelin *et al.* 1979, Addison *et al.* 1983, and Welch *et al.* 1985). Each discusses a different technique.

Robbins (1983) provides a good basic list of items to consider when preparing a formulated milk replacer for raising orphans. Milk formulation is important. Proper balancing of sugars and fats of similar composition to maternal milk is desirable. If fat is added, butterfat is preferred but animal tallow or egg yolks can also be used. When significant levels of fat are added, homogenize the milk to ensure maximum fat dispersion and minimal fat droplet size. These measures will maximize digestibility. Added fats that produce severe diarrhea include vegetable fats, primarily common cooking oils. Avoid feeding milk higher in fat content than the species normally produces. Moose milk contains about 25-32% total solids, 5-12% fat, 14-19% crude protein, and 2-6% lactose (Franzmann *et al.* 1975, Renecker 1987).

The volume of replacer fed at each feeding is important. Excessive feeding can result in diarrhea, listlessness, potbellies, and death. Neonates are rarely capable of regulating milk intake (Robbins 1983). Addison *et al.* (1983) felt that excessive diarrhea in moose calves raised in Ontario was directly related to the volume of milk replacer fed. They recommended that calves not be fed more than 2.5 l/day, and volume increases in formula should not exceed 10-15%/day. Similarly, avoid underfeeding.

Often the best indicator of feeding level is the health and vigor of the calf. Rates of weight gain in healthy calves are around 1.5%/day (Schwartz *et al.* 1987b) which is about 0.3 kg/day in young calves and as much as 1.4 kg/day in late summer calves.

Eighty-six percent of the facilities bottle-raised calves. Eighteen facilities raising moose calves, including the MRC, provided usable data summarizing their techniques (Table 1). Diets varied but most (44%) facilities used a mixture of whole cow's milk and evaporated milk. Mixtures ranged from 5 to 1 part(s) whole (4% fat) homogenized cow milk per part of evaporated milk (Table 1). Six (33%) of the facilities used commercial cow milk replacers (various brands) either alone or mixed with whole cow or goat milk. Three (16.7%) used evaporated milk diluted with water, and one facility used a product called doe milk replacer (National Food Laboratory, Inc., Dublin, CA 94568). Doe milk replacer is similar to deer (*Odocoileus spp*) milk, and contains about 29% fat compared to cow milk replacer that has about 13.5% fat. Reconstituted doe milk contains approximately 6.8% crude fat, 6.8% crude protein, and 23% solids.

Several people added egg yolks, buttermilk, casein, and/or a commercially available product called Multi-MilkTM (Pet-Ag. Inc., Elgin, Il.) to supplement the fat and protein level of their milk replacer (Table 1).

In addition to a staple milk diet, many

Table 1. Calf feeding protocol provided by 18 different zoos and research facilites bottle raising moose calves.

Facility No.	Ingredient Diet[a]	Ingredient ratio	Feeding Schedule Age(weeks):vol(l)/day:feedings/day	No. fed	% raised	Weaning date
1	CM:EM:EY[b]	2.5:1:1[b]	0-2:1.8:6, 3-7:2:4, 8-11:1.5:3, >11:0.9:1	7	86	late-Sep
2	CM:EM	2.0:1	1:2.25:5, 2-3:2.5:5, 4-5:2.7.5:5, 6-7:2.4:4, 8:1.8:3, 9-12:1.8:2	8	100	12 weeks
3	CMR:CM	1.5:1	0-12:2.5-6.0:5 depending upon age		60	mid-Aug
4	H2O:EM:EY[c]	2.0:1:2[c]	all ages:2.0-4.0:4 depending upon age		75	not provided
5	CM:EM	5.0:1	0-4:2.0:8, 5-8:>2.0:6, 9-12:>2.0:4	28	75	by 4 months
6	EM:H_2O	1.0:1	1:30ml/kg, maximum of 2000ml:?, increase ratio to 2:1 >week 1		poor	40 days
7	CMR		0-3:1.5:6, >3:2.4:5	14	36	late-Aug
8	EM:H_2O	1.0:1	all ages:20mg/kg:5 or 4		99	4 months
9	CM:EM	1.0:1	0-3:2:6, 4-7:2.5:4, 8-12:reduced to 0		50	12 weeks
10	CM:EM	2.0:1	0-5:2.1:5, 6-7:1.75:4, 8-9,1.25:3, >9:0.3:2,	18	100	10 weeks
11	DM		0-4:2.8:3, 5-8:2.85:2, 9-12:1.4:1	2	50	mid-Aug
12	GM:CMR	1.0:1	all ages:3.2-4.0:4	3	100	12 weeks
13	CM:EM[d]	2.5:1	0-8:2-6:4 lamb replacier after 8 wks		100	12-16 weeks
14	CM:EM	2.0:1	0-6:2.5:4, 7-12:3.5-1.0:4, reduce to 1 liter by age 12wks		70	late-Aug
15	CMR		0-4:2.1:6, 5-8:1.9:4, 8-12:1.2:4-1	16	81	early-Sep
16	CM:EM:EY[e]	1.0:1:4[e]	0-4:1.1:6, 5-12:1.4:4, 13-16:1.9:4		90	4 months
17	CMR		0-2:2.4-3.4:5, 3-4:3.8-4.2:5, 5:3.3:4, 6-9:2.9:3, 10-14:1.8-0.9:2-1	39	59	late-Aug
18	CMR[f]		all ages:25 mg/kg:8	25	36	12-16 weeks

[a]CM=whole homoganized cow milk, EM=evaporated milk, CMR=cow milk replacier, H_2O=water, GM=goat milk, LMR=lama milk replacier, EY = egg yolk.

[b]One egg yolk was added to 1 liter whole cows milk mixed with 1 can evaporated milk (385ml).

[c]Two egg yolks were added to 1 can evaporated milk with 2 cans water.

[d]Thirty mls of buttermilk was fed once per day.

[e]Four egg yolks were added to 1 pint can evaporated milk and 1 pint cow milk.

[f]Caseine was added to the milk to bring the crude fat level to 24%.

facilities indicated that they provided mineral and vitamin supplements orally (mixture in the formula) or as an injectable. Both fat (A, D, E) and water soluble vitamins (B-complex) were used. Injectable vitamins, although requiring additional time to administer, insured proper absorption, while those orally administered may not be absorbed if the calf was experiencing any digestive inflammation associated with diarrhea.

Two facilities used injectable selenium to prevent white muscle disease. We have also used this at the MRC, where we have had at least one documented fatality in an orphaned calf attributed to white muscle disease.

Two facilities fed their calves probiotics (gastrointestinal tract microbial product) to ensure a healthy development of lower gut flora. These products are relatively new, manufactured for domestic livestock, but may prove beneficial for rearing moose calves. Their function is to reduce diarrhea; they also enhance dry matter intake.

The amount of milk fed to calves depends upon the size of the calf and the concentration of nutrients in the milk itself. Most facilities fed each young calf 2-2.5 liters/day (range 1.1-3.8 l/day), in 5 or 6 feedings (range 3-8) spaced throughout the day (0600-2200 hrs) (Table 1). A few facilities indicated that they fed young calves (generally < 2 weeks of age) during the early-morning hours (0200 hr). Three facilities fed bovine colostrum mixed with the formula the first week.

Milk volume increased and feedings per day decreased as calves aged. Generally milk volume fed to calves peaked when calves were 6-8 weeks of age, to a maximum (2.5-4 l/day, range 2.0-6.0); the number of feedings per day declined to 3-5 (range 2-6). Most people weaned calves at 12 weeks of age (late-August) but one facility weaned at 10 weeks and several waited until late-September when calves were 16 weeks old. Weaning was gradual with a reduction in milk volume and feedings/day.

Calf moose began sampling solid foods as early as 3 weeks of age, and readily consumed solids by one month of age. Virtually everyone raising calves offered browse (willow, birch, aspen, fireweed), formulated rations, trace mineral salt, soil, and water. Many indicated the sooner calves were switched from milk to solid foods the greater their chance of surviving.

Many people provided additional suggestions that warrant discussion. Besides good hygiene and immediate attention to diarrhea, which will be discussed in more detail later, keen observation and "tender loving care" were two suggestions most commonly listed. Moose calves responded to attention and were highly interactive with their caretaker. This interaction was the only substitute for the mother-young bond and likely served to calm the calf. During these interactions, caretaker noted changes in appetite, brightness of eyes, general vigor, and possible looseness of stools.

Several people suggested that calves did best when raised outside; one person indicated that their calves did poorly when kept indoors in a heated building. The best option was to rear calves in a large pen containing adequate vegetation and food. One facility kept calves in close confinement for the first 2 weeks of life and then released them into a large pen. These calves were "called home" at feeding times, but foraged on natural vegetation during the remainder of the day. This technique reduced the need for an elaborate rearing pen and substantially reduced labor cost to keep it clean. Calves reared this way remained tractable because of their continued dependence upon bottle feeding.

Other useful suggestions included treating the umbilicus of newly born calves with iodine to reduce infections, isolation of sick animals, and regular replacement of bedding.

Feeding Adults—Only 2 of 26 (8%) facilities kept moose in pastures large enough to sustain them on natural browse. The remaining 24 (92%) fed moose a formulated diet, and 21 (88%) supplemented the ration with natural browse. In most cases, browse was harvested and taken to the moose, although 4 facilities indicated that some natural browse and/or aquatic plants were available within the holding pens.

Formulated rations were generally a mixture of cereal grains (corn, oats, barley) for energy, soybean meal for protein, and woodfiber (sawdust) or hay as a fiber source. They also contain vitamins, minerals, flavors, and usually a product to enhance pelleting.

Of 25 facilities providing the composition of their ration, 18 (72%) used sawdust based diets, 4 (16%) used alfalfa (*Medicago sativa*) based diets, and 3 (12%) fed wood fiber and grain. The most common diet listed was the one we use at the MRC (Schwartz *et al.* 1980, Schwartz *et al.* 1985). The diet contains an aspen byproduct (Table 2) as the fiber source, is about 56-60% digestible, and has a crude protein content of 10-12%.

Five facilities listed 3 modifications to this diet. Two facilities substituted sunflower hulls for the aspen sawdust (Syroechkovsky *et al.* 1989:375). Chemically, sunflower hulls are similar to wood fiber (Anon. 1971), with lignin being the main fiber type. This sunflower hull diet was probably an adequate substitute, although neither facility fed it to moose for more than 4 years. Long-term testing will determine diet success. One facility reduced the amount of corn and increased the concentration of soybean meal to raise the crude protein content to 14%. Two other facilities substituted 10% alfalfa meal for part of the energy grains. Both facilities were small and kept only a few moose. Neither facility experienced digestive problems in adult moose.

Two facilities used a formulated ration that contained about 30% dehydrated alfalfa as the fiber source. Two facilities used a commercial brand of dairy or deer ration, but failed to provide me with the ingredient label. I assumed the source of fiber was alfalfa. One facility used the deer ration to supplement moose feeding in a large natural pasture. At one of the facilities, chronic digestive upset resulting in death was evident from necropsy reports.

Three facilities provided wood fiber along with concentrates. One facility fed oats, peas, and poplar sawdust. A second fed hay helper (product name and formula not provided) mixed with 10% birch sawdust. The third fed a 50:50 mixture of an aspen bark product (80% aspen bark, 10% rolled oats, and 10% rolled corn, resulting in 3.7% crude protein) and commercial concentrate (equal amounts of corn, oats, and barley plus molasses). One respondent listed laminitis as a problem in adult bulls, but did not indicate if it was related to diet. At one facility they recently changed diets because of chronic diarrhea in adults and hoped the inclusion of wood fiber would cure the problem.

A new diet currently being fed by one zoo is the Mazuri Moose Maintenance Diet (Purina, Saint Louis, Mo). The primary ingredient, wood flour, is aspen sawdust sized to pass through a pelleting machine. The diet contains 11% crude protein. It differs from the MRC diet because it contains alfalfa meal and sucrose. Sucrose is the energy source replacing the corn, barley and oats in the MRC diet. Sucrose is a readily digestible carbohydrate. The manufacturer suggests that diets high in starch (energy source in cereal grains) cause digestive problems in moose. They feel that flora in the rumen of moose inadequately digest starch. This undigested starch then passes into the lower gastrointestinal tract. Fermentation of starch in the lower gut results in chronic diarrhea (B. Sadler, pers. comm.). No published data or controlled studies were available to support these claims. The company is currently testing the diet at selected zoos. Purina also manufactures a breeding diet (Mazuri Moose Breeder) which contains 16% crude protein and more digestible en-

Table 2. Composition of the Moose Research Center ration.

Ingredient	%
corn, ground yellow	30.0
Sawdust	25.0
Oats, ground	15.0
Barley, ground	12.5
Cane molasses, dry	7.5
Soybean meal (7.4% nitrogen)	6.3
"Pelaid"[a]	1.3
Dicalcium phosphate	1.1
Sodium chloride	0.5
Vitamin A-D-E[b]	0.3
"Mycoban"[c]	tr
Trace minerals and flavors[d]	tr

[a]"Pelaid" (Rhodera Inc., Ashland, Ohio) is a pelleting enhance.

[b]Each kg feed contained 5,000 IU Vitamin A, 13,000 ICU Vitamin D_3 and 44 IU Vitamin E.

[c]"Mycoban" (Van Waters and Rogers, Anchorage, Alaska) inhibits mold growth, tr = 0.025%.

[d]Added trace minerals and flavors (mg/kg) Zn, 55.2; Fe, 30.5; Mg, 22.0; Mn, 16.8; Cu, 7.6; I, 1.3: and anise, 125.

ergy. If these diets prove successful, availability of a formulated moose ration will improve.

Dr. C. T. Robbins at Washington State University has also formulated a starch free test ration for moose (Table 3). He has successfully fed this diet for more than 2 years. A bull consuming the MRC ration with indications of diarrhea produced normal pelleted feces when switched to this diet. Controlled experiments evaluating starch digestion in moose seem warranted.

Since this survey was conducted (1990) and the time of printing (1992), 3 facilities have tested the Mazuri ration. Two of three facilities are pleased with the diet. One offered both the Mazuri and MRC diets in combination and noted that the animals switched freely between the two, consuming more of one diet during certain times, but less during others. The third has experienced some digestive problems with one animal, but the cause was uncertain.

Besides offering formulated diets and browse, several facilities (36%) regularly feed produce (carrots, apples, bananas, lettuce, cabbage) and bread. Many people felt these foods were enjoyed by the animals and served as a dietary treat. Almost 20%, supplemented moose diets with hay, mainly alfalfa or an alfalfa-brome mix. One facility supplemented with grass hay and another with clover hay. No one fed grass hay alone or as the major dietary item.

Food Consumption Rates—Our experience at the MRC indicates that food consumption will vary with season and sex of moose. Both males and females consume about 2.5-3% of their body weight of dry feed in summer. They reduce this level to 0.5-1.0% of body weight in winter (Schwartz *et al.* 1984). Reduced consumption in winter is voluntary and no reason for alarm. Bulls do not eat during the rut for as long as 3 weeks; this fasting is normal (Schwartz *et al.* 1984). Consumption rate of a formulated diet declines as browse is made available, particularly if browse contains green leaves. During summer when consumption rates are high, loosely formed stools resembling "cow pies" are common. Healthy animals produce typical moose pellets during winter.

Weaned calves consume about 1.5-2.5% of their body weight/day. Calves will maintain a relatively high rate of intake during winter and continue to gain weight (Schwartz *et al.* 1984, Schwartz *et al.* 1987b).

Table 3. Composition of the Washington State University moose ration.

Ingredient	%
Sawdust	22.5
Canola meal	20.0
Beet pulp	18.8
Alfalfa meal	10.0
Molasses (dry)	8.0
Sucrose	7.5
Wheat bran	5.0
Bone meal	5.0
Animal fat	0.75
Trace mineral salt[a]	0.75
Lime	0.50
Dicalcium phosphate	0.05
Vitamin premix[b]	0.25
Vitamin A premix	0.225
Se premix (0.02% Se)	0.150
Vitamin E premix (500 IU/g)	0.070
Vitamin K premix (0.14 g/g)	0.005

[a]Trace mineral salt: 96-96.5% NaCl, 0.20% Mn, 0.35% Zn,).20% Fe, 0.15% Mg, 0.03% Cu, 0.007% I, and 0.005% Co.

[b]Vitamin premix: 400,000 IU A/lb, 30,000 IU D_3/lb, 2,000 IU E/lb, 360 mg B_2/lb, 1,200 mg niacin/lb, 1,200 mg d-panothenate/1b, 45,000 mg choline/1b, 1.8 mg B_{12}/1b, 90 mg menadione sodium bisulfite/1b, 100 mg folic acid/1b, 9 mg d-biotin/1b, and 4,540 mg ethoxyquin/1b.

Bulls reach peak body weight in late-August or early-September just before rut and velvet shedding. They can lose up to 20% of this weight during the rut, but generally regain body condition in November and early December. Overwinter weight loss in bulls ranges from 7% to 23% depending upon conditions. Cows reach peak body weight in mid-winter, much later than males, and minimum weights occur after parturition. Average weight loss ranges from 15-19% (Schwartz *et al.* 1987b).

This past winter, we experienced a decline in intake associated with a change in the diet constituents of the feed. Our feed manufacturer replaced dry cane molasses with liquid molasses. Although the change appeared minor, we experienced more than a 50% decline in food intake; several moose refused to eat this new diet. We are unsure why liquid molasses made the ration less palatable, but suspect ingredient quality, concentration, odor, and possibly discriminating individuals. This incident does suggest caution when altering diet make-up.

Breeding

Fourteen facilities breed moose. Twelve facilities breed cows as soon as they reach sexual maturity, whereas 2 did not breed yearling. At the MRC, annual calf production over at least a 10 year period for each cow averaged 1.5 calves for females (n = 4) that were first bred as yearlings and 1.9 calves for females (n = 3) first bred as 2-year-olds. These data suggest calf production over the breeding life of a cow may improve by not breeding females as yearlings; additional research is needed.

Sexual maturity and age of first reproduction in moose are directly related to body size and nutrition (Simkin 1974). In captivity, females first breed at 1.5 (57%), 2.5 (29%) or 3.5 (14%) years-of-age. This high rate of reproduction in yearlings indicates the high plane of nutrition of captive reared moose. At the MRC, we have had 10 of 13 females (77%) breed as yearlings.

Primiparous females consistently produced a single calf, although 2 sets of twins were reported. At the MRC, 1 yearling cow out of 10 produced twin calves. Facilities indicated that adult females produced either 1 (65%), 2 (10%), or 1-2 (25%) calves. Few facilities provided reproductive histories of individual females. At the MRC, of 31 births by mature cows, 58% were twin and 42% were single births; we have never had triplets. Our overall productivity of calves from all females averaged 1.5 calves/birth.

No respondent felt they had major reproductive problems. Minor problems included: still births (n = 12), adult cows not producing calves (n = 3), dystocia, difficulty birthing, or breached births (n = 4), spontaneous abortions (n = 2), deformed calves (n = 2), retained placenta (n = 2), uterine inertia (n = 1), and failure to come into heat (n = 1). In addition, several people (38%) indicated that their cows gave birth to small, generally frail calves that died shortly after birth (n = 25). Several people cautioned about the potential danger to caretakers from rutting males.

Herd Health Problems

Calves—Diarrhea is a common problem experienced by most facilities raising calves. Loose stools seem to be inevitable with bottle-raised calves and should not be cause for concern unless they are severe. Severe diarrhea involves loose, watery feces, which is often foamy and released involuntarily. Chronic long-term diarrhea ultimately results in weight loss, dehydration, and in severe cases, death. A number of facilities treat diarrhea with medications, primarily Kaopectate (Upjohn Co., Kalamazoo, MI 49001) or some other brand of anti-diarrhea medicine available at the local pharmacy. A few facilities also use sulfa drugs. A common practice to help alleviate diarrhea is to eliminate milk from the diet for one to several feedings and substitute an electrolyte solution that contains glucose.

A second problem that appears related to bottle-raising calves is laminitis or foundering. Foundering in young ruminants is caused by carbohydrate overload that results in degeneration and inflammatory changes in the laminae of the hoof (Jubb *et al.* 1985). Extreme changes in diet quality and volume cause laminitis in bottle-raised moose calves. Calves can live with the affliction, but as they mature their weight, the leverage force placed on the toes, and the pulling forces of certain tendons results in poor alignment of the foot and leg bones. There is a general elongation of the hoof and varying degrees of pain and difficulty associated with walking.

Polyarthritis and meningitis are two ailments that afflict bottle raised calves. Both can result from a general septicemia associated with microbial infections. Invasion may occur through a wound or in very young calves through the umbilicus (Timmermann and Lancaster 1978).

Adults—Several of the reporting facilities provided necropsy records and/or listed the cause of death for animals dying at their facility. I reviewed these reports and categorized deaths into infectious and noninfectious categories that I subdivided further (Table 4).

Infectious diseases accounted for 32% of all deaths. Bacterial and viral agents were responsible for 69% of infectious diseases. Moose died with pneumonia, systemic infections, gastroenteritis, and malignant catarrhal fever. Malignant catarrhal fever is a viral infection that is lethal to moose. Domestic sheep and other members of the sheep and goat family (*Bovidae*) carry the disease. In 2 cases, Ibex (*Capra aegagrus*) and domestic sheep were the suspected reservoir.

The other form of infectious disease responsible for 10% of the deaths (31% infectious deaths) was parasitic meningeal worm, whip worm, thread worm, and hydatid cysts (Table 4). Surprisingly meningeal worm (*Parelaphostrongylus tenuis*) was only reported once in spite of the very common

Table 4. Reported cause of death for 45 adult (age > calf) moose held in captivity in zoos, game farms, and research facilities in North America.

Cause of death	n	%	Comments
Infectious		32	
Bacterial or viral		22	
Gastroenteritis	2	4	*Salmonella spp, Escherica coli*
Malignant catarrhal fever	3	7	carried by sheep and goats
Pneumonia	5	11	may have been secondary agent
Parasitic		10	
Brain worm	1	2	*Parelaphostrongylus tenuis*
Whip worms	2	4	*Trichuris* spp.
Thread worms	1	2	*Trichostrongylus* spp.
Hydatid cyst	1	2	*Echinococcus granulosis*, pneumonia
Noninfectious		67	
Man-caused	7	16	Complications during immobilization
Nutritional	6	13	poor body condition, teeth, chronic wasting
Digestive upset	14	31	chronic diarehha, gut ulceration, torsion,
Arthritis and laminitis	3	7	predisposed to pneumonia or poor nutrition

practice of mixing hoofed stock, particularly white-tailed deer (*Odocoileus viriginianus*) and wapiti (*Cervus elaphus*) with moose. Both carry *P tenuis*, which is lethal to moose (Lancaster 1987).

The low percentage of deaths caused by parasites may in part be due to control measures. Most facilities routinely (2-6 times/ year) examine feces for parasites. Periodic treatment with Ivermectin was a common practice.

Noninfectious diseases and accidents were responsible for the greatest percentage (67%) of all reported deaths in adults. Drug related deaths were responsible for 16% of the known mortality, mainly from aspiration pneumonia, but also from capture myopathy.

The single greatest cause of death listed was nutritional and digestive upset resulting from chronic diarrhea. Nutritional problems ranged from starvation resulting from malocclusions and/or badly worn teeth (n = 3), injury to the tongue (n = 1), and improper feeding (n = 2). Both old and young animals had tooth problems. Other respondants reported worn teeth not associated with death. It appears that tooth problems are common to moose in captivity.

Digestive upset, often resulting from chronic diarrhea was the single most common cause of death (31%). It was difficult to determine why moose died from this ailment, but I suspect it was dietary. Animals dying from long-term chronic diarrhea and loss of body condition, generally were fed for several years on diets containing grass hays or a formulated ration containing crop residues or hay. However, 2 facilities that fed both hay-based and sawdust-based rations reported similar problems with both diets. One facility held moose in captivity for many years (>30), and the other held moose for 13 years. One facility fed browse regularly, the other rarely. Not all problems are solely dietary. There seemed to be some relationship between the number of years a facility kept moose and the degree of health problems, especially facilities with small enclosures.

As with calves, laminitis or foundering, predisposed a small number (7%) of animals to problems and death. Arthritis was less common, probably because few moose live long enough to develop the problem.

Common health problems not responsible for deaths included winter tick infestation (*Dermacentor albipictus*), biting insects, overgrown hoofs and dewclaws, and injuries to antlers. Pesticides controlled insects and ticks.

Longevity—The average life-span of a moose kept in captivity listed by those facilities responding ranged from 3-8 years, with the majority reporting 4-6 years. The longest lived animals were reported at 8-13 years of age, with the majority listed at 10-11. No facility reported keeping a moose over 13 years old. This is much younger than similar reports from wild populations where moose have been known to reach the age of 16-20 (Peterson 1955).

Several zoos provided taxon reports which list date of death for moose kept in captivity. Using these data, I constructed a survival curve (Fig. 1) which depicted life expectancy in captivity. Estimates were minimum since animals still living were not included.

The single greatest age class suffering high rates of mortality was calves. Almost 70% of all calves raised in captivity died before their first birthday. This estimate includes

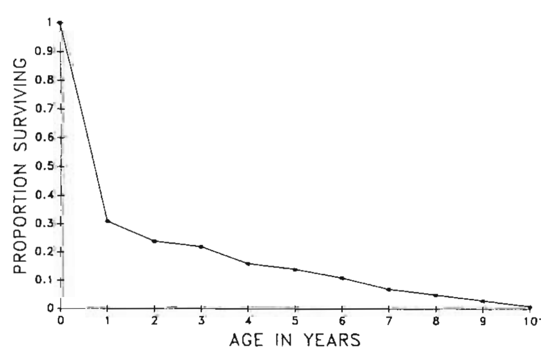

Fig. 1. Proportion of moose kept in captivity surviving by age class in North American zoos and research facilities.

all sources of mortality. Since some facilities commonly attempt to raise orphaned calves, low survival is expected. Orphaned calves are often weak, dehydrated, injured, and may not have eaten for several days. Chances of survival are low.

Compatibility of Other Species

Over half the facilities reporting indicated that they kept other species with their moose. Ungulate species included white tailed-deer (n = 6), mule or black-tailed deer (*O. hemionus*) (n = 5), wapiti (n = 6), caribou or reindeer (*Rangifer tarandus*) (n = 3), pronghorn (*Antilocapra americana*) (n = 2), bison (*Bison bison*) (n = 1), bighorn sheep (*Ovis canadensis*) (n = 1), mountain goat (*Oreamnos americanus*) (n = 1), fallow deer (*Dama dama*) (n = 1), and muskox (*Ovibos moschatus*) (n = 1). In addition to other hoofed stock, three facilities kept waterfowl and gallinaceous birds, and one facility kept black bear with the moose. The facility keeping black bears did experience some calf predation and was forced to separate the bears from the moose during calving season. No respondent indicated any behavioral problems or fighting between the mixed hoof stock and moose. Several people indicated moose were very compatible with other species.

SUMMARY

The number of facilities keeping moose in North America has increased in recent years. Commercial game farming is a growing industry (Hudson *et al.* 1989). Although bison, reindeer, and wapiti are the most profitable ungulates, moose have served in a limited way to diversify these grazing systems (Renecker *et al.* 1987). Currently, moose are raised for display or sale as breeding stock. Because moose are difficult to keep and expensive to feed (Schwartz *et al.* 1985), they are not raised for meat or milk production.

Moose are easily kept inside standard game fencing that is a minimum of 2.1 m high with post spaced 3.0-4.6 m apart. Fencing costs at least $8,000/km just for materials (Renecker et al. 1987). Holding facilities must be large with a stocking rate of about 1 moose/0.5 ha when the animals are fed supplemental rations. Few facilities keep more than 5 moose together. Due to the solitary nature of moose, keeping large numbers of animals together may be detrimental, although additional studies on social stress are warranted.

In northern climates, moose appear to do well with minimal shelter. Dense stands of trees or a 3-sided shelter provide adequate protection from winter storms and wind. During summer, temperatures exceeding 27°C can cause thermal stress and adequate cooling facilities are desirable. Trees and shelters work in northern climates, but ponds, streams, or sprinkler systems are more appropriate in hot climates.

Raising calves is a difficult task. Chronic diarrhea is the most common cause of death in bottle-raised orphans. Milk replacer made with a mixture of whole cow milk and evaporated milk or a dairy milk replacer is the most common formulas used. Success with each formula is difficult to determine, but it appears that the cow milk and evaporated milk mixed diet is slightly superior. Diet evaluation requires better record keeping. Supplements to increase the fat and protein content of diets may be useful but their needs and success require further evaluation.

Moose are a sensitive species in captivity. Meeting feed requirements appear to be the single greatest hurdle. The development of a relatively new ration that contains wood fiber in the form of aspen sawdust apparently meets both nutritional needs and physical diet structure. Its development allows for moose to be kept in captivity more easily than feeding them browse (Ellis 1987). Small amounts of grass hay fed to moose for short periods cause no apparent problems. However, necropsy reports suggested that long-term feeding of grass hay rations causes digestive upset and chronic diarrhea which can result in death. Additional research is required.

When I first developed the MRC ration (1978), I was convinced that many of the digestive problems in captive moose were dietary. Improper diet seemed to be the cause of chronic wasting in moose and facilities which kept moose for many years had more problems. It is unclear if the problems resulted from: (1) increased exposure and/or accumulation of some infectious agent, (2) an increased probability of experiencing problems with time, and/or (3) it requires time for chronic wasting to develop even in improperly fed moose.

If wasting is dietary, we must attempt to match our synthetic diets as closely as possible to the natural diets of moose. Thus we must consider more than simply classically defined "required nutrients" (e.g., protein, energy, macro and micro elements, or vitamins). Matching the natural diet means providing compounds which are possibly "essential" for reasons other than they are required in a metabolic sense. For example, moose are selective browsers and consume large quantities of secondary plant compounds (tannins, phenolics, and others). Evolutionarily, the moose has adapted to handle these chemicals. Classically, we think of secondary plant compounds as "bad" for the animal. They are compounds which the plant has produced to prevent herbivory. However, since moose evolved to accommodate such "toxins", moose may "requires" or "needs" them in a non classical sense. Tannins in diets of leaf-eating insects, for example, bind with certain viral agents and prevent infection. Insects eating diets with tannin had lower mortality rates associated with a polyhedrosis virus than insects consuming similar foods without these tannins (Keating *et al.* 1988). Domestic livestock consuming legumes which contain tannin seldom develop bloat, while those consuming legumes without tannin get bloat (Goplen *et al.* 1980). Secondary plant metabolites may serve a useful purpose in the digestive system of moose. The compounds may be responsible or aid in the maintenance of specific environments needed by lower gut flora. They may prevent infections or invasion of certain organisms. In many cases, when a "sick" moose is provided natural browse the problem clears. Something in natural foods is lacking in our synthetic rations. Sawdust based rations have partially met the challenge of matching the synthetic diet with natural foods, and removing starch may be another. However, we must continue to investigate other components that might be "required" by the animal in the non-classical sense. Advances in the field of moose nutrition will be enhanced with continued cooperation and coordination among all the facilities keeping moose in North America.

Live expectancy of moose in captivity is less than in the wild. In North America it is still difficult to keep moose under strictly confined conditions. Mortality in captivity seems to result from disease and nutritional problems. Although our understanding of the nutritional requirements of moose has increased in recent years, there is still much to learn. Chronic diarrhea has been a major problem in the past and still persists today. Proper husbandry minimizes infectious disease. Simple practices, such as not mixing moose with other ungulates that carry fatal disease or parasites seem logical. Frequent screening of feces to detect parasites and appropriate treatment with medication is necessary. Laminitis, arthritis, and hoof overgrowth can cause chronic problems. A hard substrate (near food or water source so they cross it daily) and periodic hoof trimming prevents hoof overgrowth.

Moose reproduction in captivity is similar to that in the wild. Most females reach sexual maturity as yearlings, but to maximize calf production they should probably not be bred until 2.5 years of age. Twins are common from adult cows although single calves are also produced. Calf production averages 1.5-1.8 calves/year over the life of a female. Calf survival varies, but small weak calves that die shortly after birth are common. Moose occasionally suffer from dystocia, abortion, failure to breed, and retained placenta. Although up to 5 generations of moose have been successfully maintained in captivity, most facilities routinely supplement their stock with animals from the wild.

When I set out to consolidate what has been learned about moose husbandry in North America, I had no idea what kind of responses I would receive. I was very pleased that virtually everyone keeping moose participated. If we all work together, we can continue to improve our understanding of moose requirements in captivity. Facilities keeping moose should make every effort to keep accurate herd records. Only with a clear understanding of husbandry problems will we ultimately succeed in our efforts to successfully maintain this unique deer species in captivity.

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