GROWTH AND VITAL SIGNS OF HAND-RAISED MOOSE CALVES IN ALASKA

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ABSTRACT: Moose (*Alces alces*) have been raised in captivity for research and educational purposes for decades. Past research has focused mostly on milk replacer diets to produce healthy calves, with limited research of vital signs associated with routine health checks of young animals. We hand-raised 20 calves in 4 cohorts (2009, 2012, 2019, 2021) using commercially available milk replacers mixed with water only, and measured vital signs of 11 calves in 2019 and 2021. Growth rate from birth through weaning was 0.98 ± 0.02 kg • d^{-1}, with maximum growth rate of ~1.3 kg • d^{-1} sustained for 6 weeks after weaning was initiated. Heart rate declined with age from 103.5 ± 2.6 beats • min^{-1} at 5 days old to 81.6 beats at 80 days old, whereas respiration rate increased from 16.3 ± 2.5 to 36.7 ± 4.4 breaths • min^{-1}. Respiration rate increased with ambient air temperature from 11.1 ± 2.9 breaths • min^{-1} at 9 °C to 45.2 ± 3.2 at 26 °C. Respiration rate was highly variable after 3-week old calves began daily walks in a larger enclosure and ambient air temperature increased towards the summer maxima (July). Mean rectal temperature was 38.5 ± 0.03°C, and declined marginally with increasing vapor pressure and wind speed. Our hand-raising protocol and milk replacer diets produced calf growth rates higher than those reported previously, and similar to dam-raised calves consuming pelleted ration and available grass forage.

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The wildlife profession has a long history of raising wildlife in captivity for various research and educational purposes including rehabilitation (Escobedo-Bonilla et al. 2022), supplementing wild populations (Biggins et al. 1998), disease research (Rhyan et al. 2020), nutrition and energetic studies (McWilliams et al. 2020), and outreach (Learmonth et al. 2021). Knowledge of nutritional requirements and physiological metrics necessary to assess animal welfare are foundational to raising captive wildlife species successfully. The nutritional requirements of captive wildlife, including moose, are generally well understood and met, and our knowledge of physiological metrics has improved from recent advancements in technology. For example, commercially available milk replacers for many ungulates closely match the mother's milk without need for multiple additives (Parker and Barboza 2013, Petzinger et al. 2014), and monitoring health of captive animals has improved with the use of biologgers that measure body temperature and heart rate remotely (Signer et al. 2010, Hetem et al. 2019, Thiel et al. 2022).

Developing tractable, captive moose begins with hand-raising calves from an early age. Multiple North American publications spanning 65 years (Dodds 1959, Regelin et al. 1979, Addison et al. 1983, Lautenschlager and Crawford 1983, Welch et al. 1985, Lankester et al. 1993, Shochat et al. 1997) document methods for bottle-raising calves, with the last published > 25 years ago. Prior to the mid-1990s, there was substantial variation in milk replacers including raw or homogenized bovine or goat milk, powdered milk replacers (both human and domestic livestock), evaporated milk mixed with water or milk, adding vegetable oil or egg yolks to increase fat content, and other additions such as salt and corn syrup (Dodds 1959, Regelin et al. 1979, Addison et al. 1983, Lautenschlager and Crawford 1983, Welch et al. 1985, Lankester et al. 1993). Initial studies documenting moose milk composition guided formulation of early milk replacer diets (Franzmann et al. 1975, Renecker 1987). Reese and Robbins (1994) later measured moose milk composition from parturition to weaning, which Shochat and Robbins (1997) used to develop a milk replacer by mixing goat or bovine milk with domestic lamb milk replacer. Further studies with zoo animals have produced powdered milk replacers mixed with water only that simulate milk compositions similar to the target animal (Parker and Barboza 2013, Petzinger et al. 2014, Nájera et al. 2015).

Research with captive adult moose has provided a suite of physiological metrics useful for baseline health assessments including heart rate, respiration rate, and body temperature; importantly, biologging provides these vital signs remotely after initial restraint/immobilization (Franzmann et al. 1984, Regelin et al. 1985, Renecker and Hudson 1985*b*, 1986, 1989, Herberg et al. 2018, Thompson et al. 2019, 2020). However, such data are limited for health assessments of captive or wild newborn and nursing calves (Addison et al. 1983, 2014, Shochat and Robbins 1997). Such data would also aid efforts by the Alaska Department of Fish and Game (ADF&G) that responds annually to multiple orphan moose calves, often transferring them to zoos (Woodard 2023) that could use these data to monitor calves during and after transport. Although measuring vital signs of wild moose calves is feasible through direct observation or biologging, handling wild moose calves introduces the potential of abandonment (Severud et al. 2016), hence, the best option is with captive calves during hand-raising efforts (Addison et al. 1983).

We developed a milk replacer diet of similar composition as natural moose milk (Reese and Robbins 1994) by mixing commercially available, powdered milk replacers with water only. Since formulas and feeding schedules should produce normal growth rates (Reese and Robbins 1994), we evaluated our protocol by comparing our calf growth rates with those of maternally-raised moose calves. We measured milk intake rates and growth rates of calves from newborn to weaning at 120 days old, and evaluated if body mass and growth rates differed between male and female calves. We also measured 3 vital signs (heart rate, respiration rate, rectal temperature) of moose calves, and evaluated possible effects of age and environmental conditions.

STUDY AREA

Moose calves were raised at the Kenai Moose Research Center (MRC) located in the boreal forest lowlands of the Kenai Peninsula, Alaska, USA, and operated by the Alaska Department of Fish and Game (ADF&G). Calves were initially housed in a 4 m^2 covered shelter that was within a larger 700 m^2 nursery pen. The nursery pen was shaded by 40-year-old Alaska birch (*Betula neoalaskana*) and white spruce (*Picea glauca*), enclosed by a 2.4 m high woven wire fence and protected with an electric fence. As calves grew, they accessed a 0.23 km^2 large enclosure that contained mixed age (5-120 years old) boreal forest (Alaska birch, white spruce, black spruce [*Picea mariana*], Quaking aspen [*Populus tremuloides*]) and a wetland which contained open water.

Two weather stations collected a suite of data at the MRC. In 1982 a Natural Resources Conservation Service Snowpack Telemetry Network (SNOTEL; Kenai Moose Pens (366); hereafter, SNOTEL weather station) measuring hourly precipitation (mm) and ambient air temperature (°C) was located 1.9 km from the nursery pen (Natural Resources Conservation Service 2022). In 2012, a National Oceanic and Atmospheric Administration (NOAA) U.S. Climate Reference Network weather station (AK Kenai 29 ENE; hereafter, NOAA weather station) was located 0.3 km from the nursery pen, measuring ambient air temperature, precipitation, solar radiation ($W \cdot m^{-2}$), relative humidity (%), and wind speed ($m \cdot s^{-1}$) at 5-min intervals (Diamond et al. 2013). We calculated actual vapor pressure (hPa, Alduchov and Eskridge 1996) from the dew point temperature (°C) calculated from relative humidity and ambient air temperature.

METHODS

All procedures for care, handling, and experimentation were approved by the Animal Care and Use Committee in the Division of Wildlife Conservation, ADF&G (Protocol # 09-29 and 0086). We hand-raised 20 moose calves (17 F, 3 M) in 4 cohorts during the summers of 2009 (n = 4), 2012 (n = 5), 2019 (n = 7), and 2021 (n = 4). Each cohort included captive born (n = 15) and orphaned calves (n = 5) collected from the Kenai Peninsula or city of Anchorage. During May and early June, we monitored captive pregnant moose daily by either visually checking the animal (2009 and 2012) or monitoring the VHF signal of a vaginal implant transmitter (2019 and 2021; McDonough et al. 2022). Newborns remained with the dam for a minimum of 24 h to provide undisturbed nursing and consumption of colostrum (Shochat and Robbins 1997). Upon separation, each calf was moved to a covered shelter and weighed (orphaned calves at arrival) by placing them in a nylon harness suspended from a spring scale (Chatillon IN-60; ± 0.2 kg; New York, New York, USA). We then drew blood samples from the cephalic vein for analysis of trace minerals and overall blood chemistry, and the umbilicus was dipped in a 10% povidone-iodine solution to reduce the risk of infection. Each received a 0.5 mL subcutaneous injection of vitamin A-D, a 1.0 mL subcutaneous injection of vitamin E and selenium (BO-SE, Intervet, Summit, New Jersey, USA), and a 3 mL oral bovine rota-coronavirus vaccine (CalfGuard, Zoetis, Parsippany, New Jersey, USA). We used uniquely colored parachute cord as an identification collar until 2 weeks of age, at which time we deployed an expandable VHF collar with uniquely colored duct tape (Mod-415-3, Telonics, Mesa, Arizona, USA). We began walking calves within the larger enclosure when we were confident they would follow; all were regularly walked by 21 days old.

We used two primary commercial powdered milk replacers to formulate milk of similar composition to moose milk (Reese and Robbins 1994, Shochat and Robbins 1997). We fed the first 3 cohorts (2009, 2012, and 2019) a mixture of 16.1% Zoologic® Milk Matrix 30/52 (Table 1; PetAg Inc., Hampshire, Illinois, USA), 5.4% Foal-Lac Powder (Table 1; PetAg Inc.), and 78.5% water that provided a metabolizable energy content of 1.12 $kcal \cdot g^{-1}$ wet weight (Table 1). In 2021, due to unavailability of Zoologic® Milk Matrix 30/52, we fed a mixture of 20.9% MooseGro (Table 1;

Table 1. Nutritional components of powdered milk formula (Zoologic® Milk Matrix 30/52; Foal-Lac® Powder; Moose-Gro) and pelleted ration (Reindeer 13% Pellet) fed to hand-raised moose calves at the Kenai Moose Research Center, Kenai Peninsula, Alaska, USA. Values per gram of dry powder for milk replacer, and per gram dry mass for pelleted ration. † Nutritional analysis provided by the manufacturer; values may vary from those listed on product label.

	Milk Matrix 30/52†	Foal-Lac® Powder	Moose-Gro†	Reindeer 13% Pellet†
ME (kcal • g^{-1})	5.95	3.73	5.10	2.18
Fat (g • g^{-1})	0.56	0.14	0.40	0.02
Protein (g • g^{-1})	0.31	0.19	0.28	0.16
Calcium (mg • g^{-1})	10.90	10.50	11.00	8.90
Phosphorus (mg • g^{-1})	7.53	7.00	8.50	5.30
Copper (μg • g^{-1})	10.00	22.00	10.00	29.90
Selenium (μg • g^{-1})	0.20	0.10	0.30	1.01

Grober Nutrition, Cambridge, Ontario, Canada) and 79.1% water that provided a metabolizable energy content of 1.07 kcal • g^{-1} wet weight (Table 1). We mixed the dry milk formula with warm water to solution in a 3 L plastic jug; milk was refrigerated (2-3 °C) between feedings for no more than 24 h.

Calves were first fed from glass beer bottles (350 mL) with sheep nipples (Addison et al. 1983, Parker and Barboza 2013), and eventually from larger plastic bottles (2 L) with calf nipples (Shochat and Robbins 1997; Milk Specialties Global, Eden Prairie, Minnesota, USA). To facilitate milk flow, we enlarged holes in the sheep nipples and crosscut openings in the calf nipples (Shochat and Robbins 1997, Parker and Barboza 2013). We weighed milk replacer (g) into individual bottles and warmed the milk in a water bath (55 °C) to body temperature (~38 °C) prior to feeding (Addison et al. 1983, Shochat and Robbins 1997, Parker and Barboza 2013). All bottles, nipples, and mixing equipment were pre-rinsed in lukewarm water (38 – 45 °C) immediately after use, then hand-washed with brush and soap in hot water (55 – 60 °C), rinsed 3 times in hot water, and air dried before the next use. We sterilized all feeding equipment once weekly by submerging it for 10 min in boiling water, then air drying.

We fed the calf milk replacer relative to individual body mass, with daily intake rates ~9% of body mass (Parker and Barboza 2013). We initially fed calves 7 times daily (every 3 h except 0300 hr), eventually reducing to 6 feedings at 21 days old, and 5 at ~35 days old. The amount of milk replacer consumed by calves increased with age up to ~ 45 days old when body mass was ~ 45 kg. In 2009 when milk replacer exceeded 850 g • $meal^{-1}$ or 3800g • d^{-1}, calves began to show signs of gastrointestinal stress; therefore, in subsequent years we did not exceed these volumes. We began weaning calves from milk replacer at 50 days old by dropping 1 feeding (850 g • $meal^{-1}$) ~ every 2 weeks; weaning occurred at 120 days old.

In the nursery pen, we first provided water *ad libitum* in 12 L buckets, and later in a 200 L water trough. We also provided fresh forage daily by hanging fireweed (*Chamerion angustifolium*) and browse including quaking aspen, Alaska birch, Scouler's willow (*Salix scouleriana*), and Bebb willow (*Salix bebbiana*). Early in rearing we offered 10 g of fresh fireweed per calf at each meal as it was the first green forage at that time. We increased the diversity of natural forage as the calves grew and green vegetation became more abundant, providing up to ~2 kg of fireweed and ~10 kg of browse daily per moose at 100 days old. At 2-3 weeks of age, we began walking calves in the larger enclosure to forage 2-3 h daily, returning them to the nursery pen for milk feedings and security at night. When 4-5 weeks old, we began walking them twice daily, eventually leaving them alone for the entire day at 10 weeks old, only returning to the nursery pen for milk feedings and nighttime security; at 100 days of age they moved exclusively to the larger enclosure. We supplemented the diet with a pelleted ration (Table 1; Reindeer 13% Pellet, Alaska Garden and Pet Supply, Anchorage, Alaska, USA) by providing 150 g • d^{-1} at 21 days old, which gradually increased to 1900 g • d^{-1} at 120 days old. We also provided salt and trace mineral blocks (American Stockman® White Salt, American Stockman® Trace Mineralized Salt; Compass Minerals, Overland Park, Kansas, USA or comparable product) with access limited at 21-60 days old.

We documented milk intake, health, appearance, and veterinary treatment daily. Calves were weighed 1-2 times weekly on a platform scale (MP Series Load Bars; ± 0.2 kg; Tru-Test Limited, Auckland, New Zealand). We measured vital signs (heart rate, respiration rate, rectal temperature) of bedded calves until 80 days of age in the 2019 and 2021 cohorts. We measured heart rate (beats • min^{-1}) by observing the pulse in the carotid artery (Thompson et al. 2020), respiration rate (breaths • min^{-1}) by observing movement in the nostrils or flank (Thompson et al. 2020), and rectal temperature with a digital thermometer (J-188 JorVet Quick Read Veterinary Digital Thermometer; accuracy ± 0.1°C; Jorgensen Laboratories Inc., Loveland, Colorado, USA) lubricated with water-based gel (OB Lube; Jorgensen Laboratories Inc.). We disinfected the thermometer after each use by cleaning the probe with gauzes soaked in chlorohexidine solution and isopropyl alcohol.

Calves in each cohort experienced transient bouts of mild gastrointestinal distress that was treated based on severity and length of time the animal had diarrhea. First, we reduced the quantity of milk by 20% and provided this volume of electrolytes between feedings (Diaque®, Boehringer Ingelheim, St. Joseph, Missouri, USA). If diarrhea persisted >24 h or its severity increased, we replaced 1 or 2 milk meals with high energy electrolytes (Addison et al. 1983, Schwartz 1992, Parker and Barboza 2013; Entrolyte® H.E., Zoetis, Diaque®, Boehringer Ingelheim) with 40 g kaolin pectin (Durvet, Blue Springs, MO, USA) and 5 g probiotics (Probios Dispersible Powder, Vets Plus, Inc, Menomonie, Wisconsin, USA; Addison et al. 1983). Administration of antimicrobial agents was only considered when recommended by the overseeing veterinarian, and generally provided only to calves with additional signs of systemic illness (e.g., loss of appetite, fever). Daily milk intake data were censored for days in which a calf experienced gastrointestinal distress (3.8% of data).

Calves born at the MRC in summer 2016 were maternally raised as part of a separate study (Shively et al. 2019). These calves, although accustomed to the presence of humans, were not trained to walk onto the weigh scales; therefore, only a single weight was attained at 90-111 days old. We immobilized them (n = 13) between 27 and 31 August with 0.3 mg Carfentanil citrate (3 mg • mL^{-1}; ZooPharm, Windsor, Colorado, USA) mixed with 20 mg xylazine (100 mg • mL^{-1}; Lloyd Laboratories, Shenandoah, Iowa, USA) with a 1-cc dart fired from a rifle (Model 196, Pneu-dart Inc., Williamsport, Pennsylvania, USA). Each was suspended in a nylon net from an aluminum weigh pole, and measured to the nearest 1.0 kg with a load cell (model XTS4-1K; Load Cell Central, Milan, Pennsylvania, USA). We administered 2 g antibiotic (oxytetracycline, 200 mg • mL^{-1}; Boehringer Ingelheim Animal Health, Duluth, GA, USA) and antagonized the immobilization drugs with 150 mg Naltrexone HCl (50mg • mL^{-1}; ZooPharm) and 2.5 mg Atipamezole HCl (5 mg • mL^{-1}; Zoetis, Parsippany, New Jersey, USA).

We analyzed our data in STATA version 15.0 (StataCorp LP, College Station, Texas, USA). We converted daily milk intake (g • d^{-1}) to daily milk intake per body mass (g • kg^{-1} • d^{-1}). We used linear mixed-effect model regression, with individual as a random effect, to evaluate the dependent variables of body mass (kg), daily growth rate (kg • d^{-1}), heart rate (beats • min^{-1}), respiration rate (breaths • min^{-1}), and rectal temperature (°C). We evaluated body mass and daily growth rate against the categorical variables of age (week) and sex. We evaluated the physiological variables (heart rate, respiration rate, rectal temperature) against the continuous variable age (days) and the climate variables collected at the NOAA weather station including ambient air temperature, vapor pressure, solar radiation, and wind speed. No physiological measures were recorded during rain events, so precipitation was not included in these models. For the physiological models, we selected the top model using Akaike's information criterion, adjusted for small sample sizes (AIC*c*), by selecting the simplest model with the lowest AIC*c* within 2 AIC*c* units of the top model (Burnham and Anderson 2002). To minimize the effects of heteroscedacity and non-normal distributions, we used a robust sandwich estimator for the variance-covariance matrix of estimates for all regression models (Rabe-Hesketh and Skrondal 2010). We compared the body mass of hand-raised and maternally raised calves at 100 days old (range 90-112) with a paired *t*-test. All means are reported as ± SE unless otherwise indicated.

RESULTS

Ambient air temperature measured at the SNOTEL weather station increased ~ 8.5 °C from 15 May (daily mean = 7.9 ± 1.6 °C SD) to a July peak (daily mean = 16.3 ± 3.0 °C SD), then declined ~ 7.5 °C on 15 September (daily mean = 8.7 ± 2.1 °C SD). Daily minima temperatures below freezing occurred in the middle of May (-3.1 °C) and September (-2.1 °C); daily maximum temperatures occurred in the first part of July (31.0 °C).

We successfully raised 17 of 20 calves to weaning; unexpectedly, two ostensibly healthy orphan calves died in 2019. The first arrived with a 2.5 cm diameter bruise with hair missing from the forehead, and was reportedly kicked by an adult cow. This calf took the bottle and thrived for 15 d but was found dead at the 0600 hr feeding. Necropsy indicated this calf died of septicemia of unknown origin, but possibly through the subdermal hemorrhage on the head. The second thrived with similar growth rates as other calves in the cohort until 48 days old. Subsequent necropsy indicated death from *Pasteurella multocida* septicemia, a common environmental bacterium possibly entering through the umbilicus. In 2019 we also raised an orphan calf to weaning that had arrived with apparent neurological damage to the left side of its face. Although it was able to vigorously suckle milk from rubber sheep nipples, its growth rate and body mass at weaning was considerably less (30 kg) than the other calves in the cohort because it was inefficient at foraging. In 2021, a 77-day old captive-born calf broke its right femur; an x-ray indicated it would not properly heal and the animal was euthanized. Although the necropsy indicated possible osteopenia, an array of blood and bone

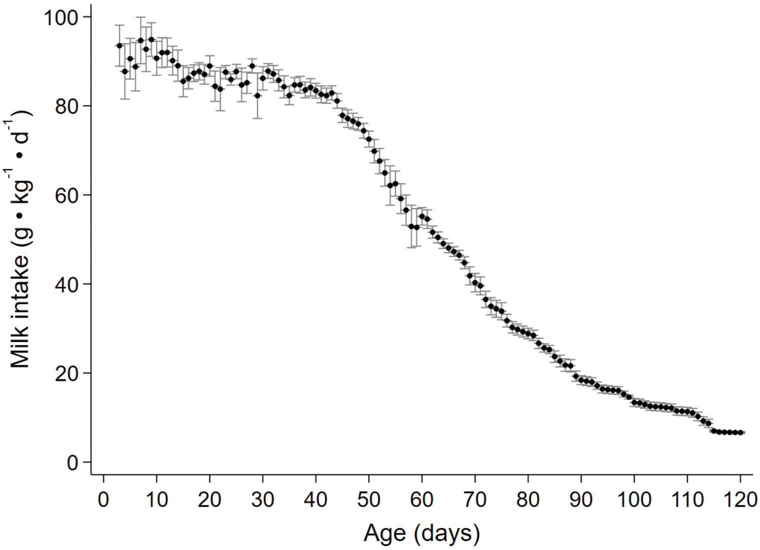

Fig. 1. Daily milk intake per body mass (g • kg^{-1} • d^{-1}; mean ± SE) of hand-raised moose calves from birth through weaning at 120 days old during 4 summers (2009, 2012, 2019, 2021) at the Kenai Moose Research Center, Kenai Peninsula, Alaska, USA.

tests provided no conclusive evidence of health-related issues predisposing the bone to break.

Daily milk intake remained stable from 3 - 44 days old (Fig. 1; mean = 0.87 ± 0.02 g • kg^{-1} • d^{-1}, range = 0.81 – 0.94) before declining when intake was limited to 3800 g • d^{-1}. Body mass of newborn moose calves was 15.4 ± 0.6 kg and increased over the summer (Fig. 2; Wald χ^2 = 22,298.1, P < 0.001), but did not differ between males and females (P = 0.357). From birth to weaning, mean daily growth rate was 0.98 ± 0.02 kg • d^{-1}. Daily growth rates increased until 9 weeks old before plateauing at ~1.3 ± 0.2 kg • d^{-1} and decreasing after 13 weeks old (Fig. 3; Wald χ^2 = 5,442.5, P < 0.001). Similar to body mass, daily growth rates were similar between sexes (P = 0.519). Body mass of hand-raised calves at 100 days old was 117.7 + 1.5 kg and less than that of maternally raised calves at the MRC (body mass = 141.9 ± 4.6 kg; t_{51} = -6.499, P < 0.001; Fig. 2).

The top model that described heart rate (n = 146) only included the variable of age (Fig. 4; Wald χ^2 = 20.7, P < 0.001; ΔAIC*c* = 0.49; ω = 0.11); heart rate declined from 103.5 ± 2.6 beats • min^{-1} at 5 days old to 81.6 ± 4.0 at 80 days old. Respiration rate (n = 171) was best described by the model that included age and ambient air temperature (Fig. 5; Wald χ^2 = 506.4, P < 0.001; ΔAIC*c* = 0.93; ω = 0.09). Respiration rate increased with age from 16.3 ± 2.5 breaths • min^{-1} at 5 days old to 36.7 ± 4.4 at 80 days old, but varied after 25 days old (Fig. 5A). Furthermore, respiration rate increased with air temperature from 11.1 ± 2.9 breaths • min^{-1} at 9 °C to 45.2 ± 3.2 at 26 °C (Fig. 5B). The best model that described rectal temperature (n = 91) included vapor pressure and wind (Wald χ^2 = 100.8, P < 0.001; ΔAIC*c* = 0.27; ω = 0.17). As wind speed and vapor pressure increased, rectal temperature declined; however, the coefficients for wind speed (-0.12 ± 0.02) and vapor pressure (-0.05 ± 0.01) were small, indicating that rectal temperature declined < 0.5 °C across the range of wind speed (0.0 – 4.1

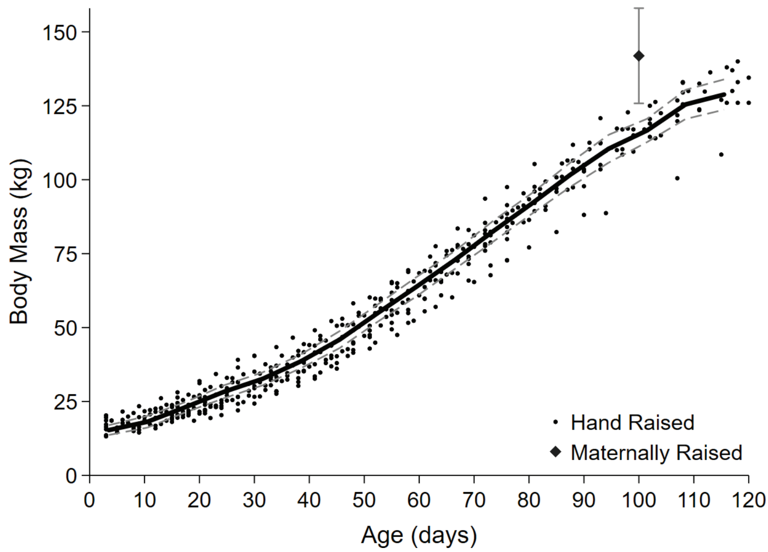

Fig. 2. Body mass (kg) of hand-raised moose calves from birth through weaning at 120 days old during 4 summers (2009, 2012, 2019, 2021) at the Kenai Moose Research Center, Kenai Peninsula, Alaska, USA. Measured (dots) and predicted body masses (solid line with dashed lines denoting 95% confidence interval) from mixed model regression against age (week). For comparison, mean body mass (± SD) of maternally-raised moose calves (diamond) at 100 days old at the Kenai Moose Research Center in 2016.

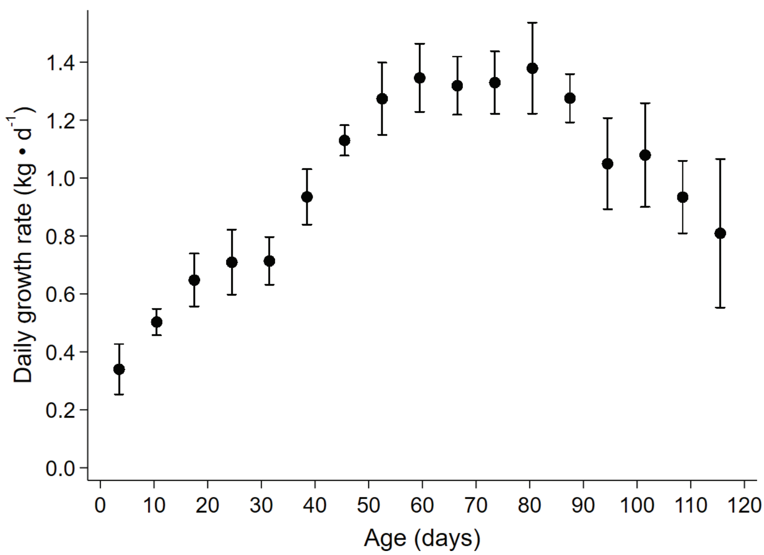

Fig. 3. Daily growth rate (kg • d^{-1}) of hand-raised moose calves from birth through weaning at 120 days old during 4 summers (2009, 2012, 2019, 2021) at the Kenai Moose Research Center, Kenai Peninsula, Alaska, USA. Solid line denotes predicted values (dashed lines equal 95% confidence interval) from mixed model regression against age (week).

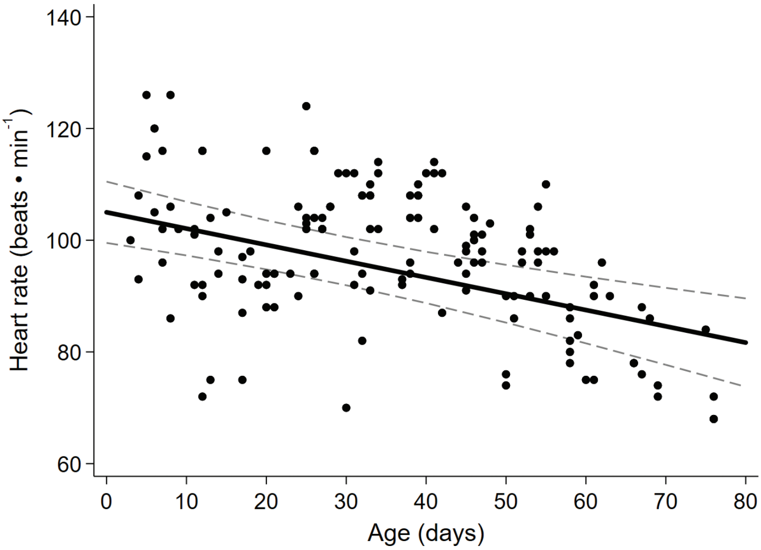

Fig. 4. Heart rate (beats • min^{-1}) of hand-raised moose calves from birth through 80 days old during 2019 and 2021 at the Kenai Moose Research Center, Kenai Peninsula, Alaska, USA. Measured (dots) and predicted heart rates (solid line with dashed lines denoting 95% confidence interval) derived from mixed model regression against age (days).

m• s^{-1}) and vapor pressure (5.5 – 13.0 hPa). The mean rectal temperature over the entire summer was 38.5 ± 0.03 °C (range = 38.0 – 39.6 °C with only 5 observations >39.0 °C).

DISCUSSION

Moose calves have high growth rates during summer to achieve sufficient body mass to survive their first winter with less per capita fat reserves than adult moose (Parker and Wong 1987, Parker 1989, Parker et al. 1990, 1993, Martin and Parker 1997). The maximum growth rate of ~1.3 kg • d^{-1} was sustained for 6 weeks after we began weaning calves, but declined as plants began to senesce in mid-August (Shively et al. 2019). We did not measure differences in growth rates between male and female calves, hence their body mass was similar at weaning. The lack of sexual dimorphism in our calves may reflect the small sample size of males (n = 3); however, Dubost (2016) found that ungulates with high sexual dimorphism as adults did not show sexual dimorphism until after weaning at 6 months.

Our daily average growth rate until weaning (0.98 kg • d^{-1}) was considerably higher than previously reported rates of hand-raised moose calves (0.49-0.78 kg • d^{-1}; Regelin et al. 1979, Welch et al. 1985, Lankester et al. 1993, Addison et al. 1994, Shochat and Robbins 1997). Our growth rate was similar to that of maternally-raised moose calves with access to pelleted ration and grass forage in Pullman, Washington (0.96 kg • d^{-1}; Reese and Robbins 1994), but substantially lower (>20%) than that of maternally-raised calves at the MRC (1.26 kg • d^{-1}). Several scenarios affecting availability and consumption of calf milk replacer, pelleted feed, and browse may have influenced the growth rate of our hand-raised calves. For example, during their first 60 days we limited the time calves spent foraging in the larger pen to 1-2 periods per day

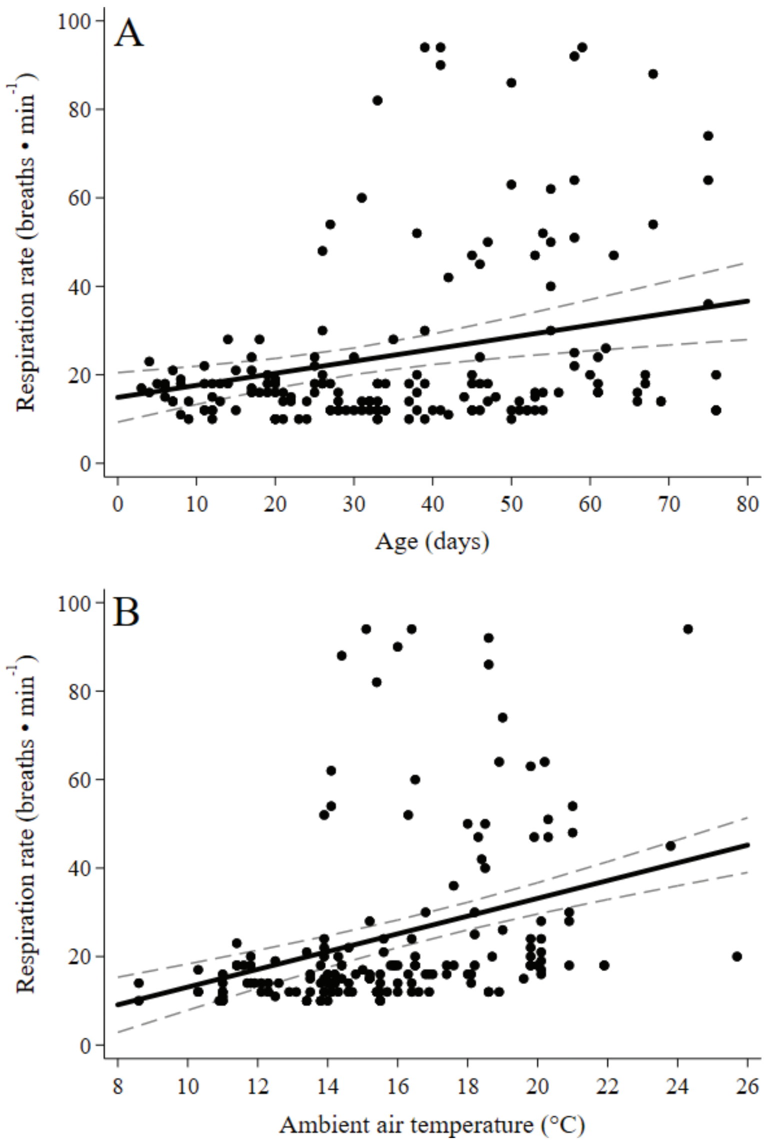

Fig. 5. Respiration rate (breaths • min^{-1}) of hand-raised moose calves against (A) age (birth to 80 days old) and (B) ambient air temperature (°C) during 2019 and 2021 at the Kenai Moose Research Center, Kenai Peninsula, Alaska, USA. Measured (dots) and predicted respiration rates (solid lines with dashed lines denoting 95% confidence intervals) derived from mixed model regression against age and ambient air temperature.

(2-3 h each). In contrast, maternally-raised calves at the MRC had 24 h access to higher availability and diversity of forage within a much larger enclosure (2.6 km^2), and presumably benefited from maternal milk and foraging experience of the dam. Increased foraging time in a larger pen and providing pelleted ration *ad libitum* may improve the growth rate of hand-raised moose calves.

Facilities that raise captive moose for research and educational purposes should understand and monitor vital signs essential to adequate health assessment of moose calves. Heart rate of young calves (1-4 days old) ranges widely (60-144 beats • min^{-1}) and at capture was > 200 beats • min^{-1} (Addison et al. 1983). Our resting heart rates at 5 days old were similar, and we also found that heart rate decreases with age at a rate of ~ 2 beats • $week^{-1}$ to 80 days old. Our resting respiration rates were also similar to rates in 1-4 days old calves (18-132 breaths • min^{-1}, Addison et al. 1983); however, we also found that respiration rates increased with age and ambient temperature. Variation in resting respiration rates greatly increased after 3 weeks of age, at which time we began walking calves in the larger enclosure and ambient air temperatures were increasing towards the summer maxima. Addison et al. (1983) reported that variation in respiration rate was associated with prior activity, and our data may partially reflect the exercise associated with walking calves. Resting rectal temperature of calves in this study was similar to that measured in prior studies (38.0 – 38.9 °C; Addison et al. 1983, Shochat and Robbins 1997), though we found that vapor pressure and wind had some influence on rectal temperature.

We lost 2 of 5 orphan calves due to septicemia, which has been documented with other orphan moose calves (Schwartz 1992, Monska 2001). Unfortunately, the circumstances surrounding why a moose calf is orphaned are often unknown, including if the calf received colostrum. Although an oral, bovine colostrum replacer could be provided to orphan calves (Shochat and Robbins 1997), and probably should, it would only aid neonatal ungulates < 36 h old as intestinal absorption of immunoglobins declines rapidly (Robbins 2001). Dairy research indicates that moose calves could receive a serum or plasma transfusion from healthy adult moose if available (Anderson et al. 1987), or possibly commercial bovine products (Chigerwe and Tyler 2010). Additionally, future analysis of serum protein concentrations and immunoglobin G levels from orphan calves could be compared to calves with known passive transfer from their mothers (Tyler et al. 1998, Wolf et al. 2021).

CONCLUSIONS

We hand-raised moose calves to weaning with a high success rate similar to that of Shochat and Robbins (1997), and our calves realized growth rates similar to captive, maternally raised calves provided grass and pelleted ration (Reese and Robbins 1994). Our protocol builds on that developed by Shochat and Robbins (1997), in that the milk replacer we used only requires mixing with water, reducing the need for large quantities of bovine or goat milk as additives and associated storage challenges for animal facilities. Increasing the availability and diversity of natural forage and pelleted ration to our calves prior to and during weaning would likely produce growth rates more similar to those of maternally raised moose calves at the MRC. We also provide unique data on physiological metrics of moose calves that varied with age, ambient air temperature, vapor pressure, and wind that should prove useful in health assessments of captive moose.

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