EFFECTS OF BIRTH WEIGHT ON GROWTH OF YOUNG MOOSE: DO LOW-WEIGHT NEONATES COMPENSATE?

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ABSTRACT: We studied the relation between birth weight and 3 measurements of body size in 10 female Alaskan moose (*Alces alces gigas*) at 10 months of age in a population where density was high (1.3 moose/km^2), compared with other areas of interior Alaska. Our study area was located in interior Alaska, USA, between the Tanana River and the Alaska Range, directly south of Fairbanks. We captured newborn (<5 days old) moose from helicopters, weighed them, and then affixed radiocollars during 14 May - 3 June 1997. These same moose were immobilized with a dart-gun fired from a helicopter, weighed, and measured during 13-16 March 1998. We used regression analyses to investigate the relationships between weight at birth and weight, metatarsus length, and total body length for recaptured individuals at 10 months of age. Positive linear relationships existed between each measure of size at 10 months and weight at birth, and were highly significant ($P < 0.02$). Further, birth weight explained significant variability in each of those 3 measurements ($r^2 = 0.63$, 0.64, and 0.53, respectively). Our results support the hypothesis that neonates with lower weights at birth in this population did not exhibit compensatory growth and remained among the smallest individuals in their cohort, at least during their first 10 months of life.

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Determining whether compensatory growth occurs in young moose under natural conditions has important management consequences. Initial weight might influence survivorship, reproduction, and ultimately, productivity of moose populations. Body weight of young moose may be one of the most important determinants of survival during winter in areas lacking large predators (Clutton-Brock *et al.* 1982, Cederlund *et al.* 1991). Additionally, body size of adults is related to reproductive performance in moose (Saether and Haagenrud 1983, Schwartz and Hundertmark 1993) and other ungulates (Clutton-Brock *et al.* 1982, Cameron *et al.* 1993, Adams and Dale 1998).

Adult ungulates can exhibit compensatory growth following undernutrition in winter (Watkins *et al.* 1990), and the potential for compensatory growth of young given unlimited food has been hypothesized (Gaillard *et al.* 1993, Schwartz *et al.* 1994). In contrast, other research indicates young ungulates lack the ability to compensate under natural conditions (Schwartz *et al.* 1994, Shultz and Johnson 1995, Pelabon 1997).

We obtained birth weights, and then other measurements of body size at 10 months of age for individual female moose. For compensatory growth to occur, low-weight young would have to gain a larger total amount of weight by the time they reached 10 months old than heavier neonates. If that compensation occurred, we would expect no relationship between birth weight and size at 10 months of age. Thus, we tested for relationships between size at birth and size at 10 months to determine if low-weight young exhibited compensatory growth.

STUDY AREA

We captured moose in interior Alaska (64° 39.17' N, 148° 07.05' W) between the Tanana River and the Alaska Range, about 25 km south of Fairbanks, Alaska, USA. This area encompasses a large portion of the Tanana Flats described previously by Gasaway *et al.* (1983). The region is underlain by permafrost and typified by poorly drained lowlands consisting of numerous shallow ponds, bogs, and creeks. Fires have created a mosaic of early successional and mature black spruce (*Picea mariana*) forests (Gasaway *et al.* 1983). Elevation within this region varies from 130 - 300 m (Boertje *et al.* 1996).

The climate is typical of interior Alaska, with cold winters, low-level temperature inversions, and relatively dry, warm summers (Gasaway *et al.* 1983). Temperatures frequently reach +25° C during summer and drop to -40° C in winter. Snow depth is generally < 80 cm, and snow pack usually remains dry and loose throughout winter.

Estimated density of moose within the study area was 1.3 moose/km^2 (Boertje *et al.* 1998). That density was high compared with other areas of interior Alaska, where populations were held at low levels by predation (Gasaway *et al.* 1992, Van Ballenberghe and Ballard 1994).

METHODS

We captured 10 newborn female moose during 15 May - 4 June 1997, and recaptured them 10 months later during 13 - 16 March 1998. All newborns we captured were singletons at birth. During spring, adult females and their neonates were located with the aid of fixed-wing aircraft. Once located, these mother-offspring pairs were approached with a helicopter and separated, at which time the helicopter landed allowing the crew to exit and capture the newborn. Neonates were weighed (nearest 0.5 kg) by placing them in a large, nylon bag and suspending them with a 25-kg spring scale (Chatillon, Kew Gardens, NY). At the completion of handling, newborns were affixed with radiocollars weighing 200 g (ATS, Isanti, MN, model 8 transmitters, 1.5 hr motion sensing switch) constructed from 4 layers of 10-cm PEG brand (Franklin Lakes, NJ) elastic bandage. We released neonates in < 5 min (even if data collection was not complete) to minimize separation time between a female and her offspring. We used latex gloves and individual weighing bags to reduce transfer of scent. The day following capture, we visually relocated young to assure that the female and her neonate rebonded. All aspects of this research were in accordance with acceptable methods for field studies adopted by the American Society of Mammalogists (Animal Care and Use Committee 1998).

All young captured were estimated to be < 5 days old based upon daily aerial locations of adult females or examination of the umbilicus, degree of hoof hardness, back posture, and knee angle of the neonate (Johnson 1951, Haugen and Speake 1958). To account for growth of neonates between birth and capture, and thus standardize birth weights, we subtracted 1.6 kg for each day the young was > 12 hr old. That correction factor was based on regression models using weights of known-age young from our population (Boertje *et al.* 1998).

We used fixed-wing aircraft and radio telemetry to locate and recapture young at 10 months of age. Once located, moose were approached with a helicopter and darted (1 cc projectile syringe propelled by a CAP-CHUR extra long-range projector). Moose were immobilized with a standardized dose of carfentanil citrate (1.2 mg) and xylazine hydrochloride (60 mg). Following darting of moose, the helicopter left the area until the animal was immobilized, at which time helicopter and crew returned to process the moose. While immobilized, weight (nearest 1.0 kg), metatarsus length (nearest 0.5 cm), and total body length (nearest 1.0 cm) were measured. We measured metatarsus length as the straight-line distance between the proximal end of the astragalus and the distal end of the metatarsus. We measured total body length dorsally along the contour between the top of the nasolabial spot on the nose and the base of the tail. To obtain body weight, moose were placed in a nylon sling and suspended from the helicopter. An electronic strain gauge (450-kg, Cardinal Scale Manufacturing Co., Webb City, MO) was linked between the net and the sling line. We used linear regression to examine relationships between birth weight and measures of body size at 10 months of age (SAS Institute Inc., Cary, NC). SAS was also used to conduct tests of normality (Shapiro and Wilk 1965) on regression residuals.

RESULTS

Newborn female moose averaged 16.3 kg (SD = 2.77 kg, range = 12.4 - 21.3 kg, n = 10). At 10 months of age their mean weight was 148.9 kg (SD = 23.94 kg, range = 123 - 200 kg, n = 10). Metatarsus length at 10 months of age averaged 50.3 cm (SD = 1.65 cm, range = 48.0 - 53.0 cm, n = 10) and total body length averaged 205.7 cm (SD = 8.42 cm, range = 193 - 219 cm, n = 10).

Our analysis of regression statistics indicated that significant and positive relationships existed between birth weight and weight at 10 months (Fig. 1), birth weight and metatarsus length at 10 months (Fig. 2), and birth weight and total body length at 10 months (Fig. 3). Birth weight accounted for a significant portion of the variability observed in each of these estimators for size at 10 months of age. Regression residuals did not differ from normality ($P > 0.2$), indicating linear regression was appropriate.

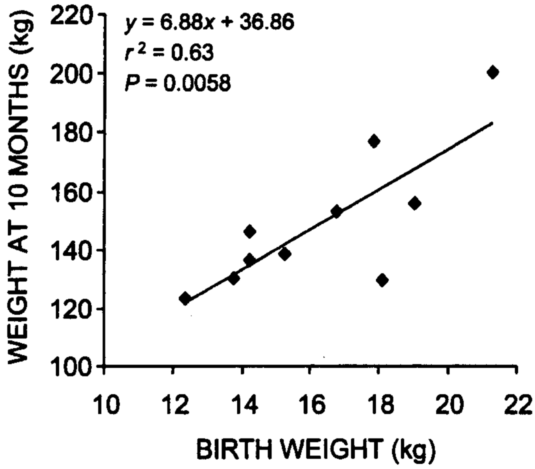

Fig. 1. Relationship between birth weight and body weight at 10 months of age for female moose in interior Alaska, USA, 1997-98. Note that this significant regression indicates the absence of compensatory weight gain.

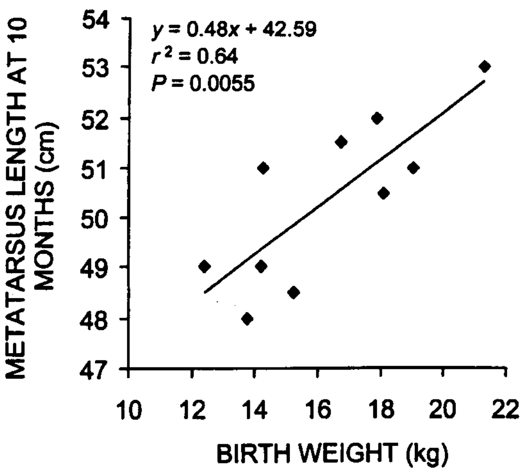

Fig. 2. Relationship between birth weight and metatarsus length at 10 months of age for female moose in interior Alaska, USA, 1997-98.

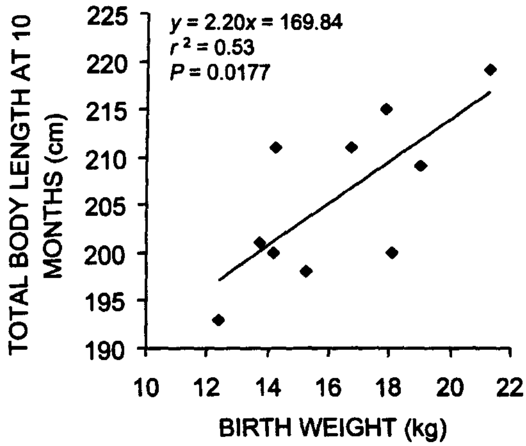

Fig. 3. Relationship between birth weight and total body length at 10 months of age for female moose in interior Alaska, USA, 1997-98.

Regression analysis was also used to examine the relationship between body weight at 10 months and the 2 measures of structural size at that age. Both metatarsus length ($r^2 = 0.72$) and total body length ($r^2 = 0.82$) were highly correlated with body weight. The regression equation for the relationship between metatarsus length and body weight was $y = 0.06x + 41.65$, ($P = 0.0019$), and between total body length and body weight was $y = 0.32x + 158.15$, ($P = 0.0003$).

DISCUSSION

We observed strong relationships between body weight and other measures of body size at 10 months of age. These results are similar to previous measurement-weight relationships reported by Franzmann *et al.* (1978). Furthermore, positive relationships between birth weight and our measures of body size at 10 months indicated that young moose in our study population could not compensate for low weight at birth. Thus, low-weight neonates remained among the smallest individuals in their cohort through the end of their first winter of life (Figs. 1, 2, and 3).

We hypothesize low birth weight may be one component that predisposes an individual to decreased likelihood of overwinter survival, increased age at first reproduction, and decreased fertility as an adult. Additionally, if the average birth weight for a population is considered over time, that metric may provide an index to predict productivity of the population because reductions in size may be expressed across generations (Mech *et al.* 1991).

Cederlund *et al.* (1991) concluded small young not only lost a larger proportion of their body mass, but also more absolute weight than did larger young during winter. If the relationship we observed between birth weight and size at 10 months of age is widespread, young with low birth weight may be predisposed to higher overwinter mortality than heavier neonates. Clutton-Brock *et al.* (1987) provided supportive data regarding red deer (*Cervus elaphus*), concluding that birth weight influenced overwinter survival of young.

An important difference between studies in Alaska and those of Cederlund *et al.* (1991) and Clutton-Brock *et al.* (1987) is the presence of large mammalian carnivores in Alaska. Predators have the potential to reduce the recruitment of young moose independent of physical condition (Gasaway *et al.* 1992, Bowyer *et al.* 1998) and alter reproductive costs of adult females (Testa 1998). Caution should be used in inferring survivorship of young from birth weights where predation by large carnivores influences the density of moose populations. Our population is at relatively high density for interior Alaska, and our observation may be the result of increased density-dependent competition for food. Nonetheless, we observed high survival of young during 1996 and 1997 (58-59%) in our study area.

If birth weight, and thus weight of 10-month-olds, is a predictor of body size beyond 1 year of life for moose, as suggested by Shultz and Johnson (1995) for white-tailed deer (*Odocoileus virginianus*), potential consequences for individuals of low birth weight include increased age at first reproduction and decreased fertility as adults. Body size and condition are related to age at first reproduction (Saether and Haagenrud 1983, 1985; Heard *et al.* 1997) and adult fertility (Sand 1996, Heard *et al.* 1997) in moose. This outcome has been documented in other cervids as well (Ozoga and Verme 1982, Albon *et al.* 1986, Cameron *et al.* 1993, Crête and Huot 1993, Allaye Chan-Mcleod *et al.* 1995, Adams and Dale 1998).

The failure of young moose to exhibit compensatory growth may be the result of several processes. First, density-dependent mechanisms may lower per capita availability of forage to both females and young, and influence the amount of maternal investment females provide to young via lactation. The amount of nutritious forage available to the female constrains her ability to provision young adequately (Loudon 1985). Second, climate may affect availability of forage to females during spring, and consequently limit suckling by neonates (Rachlow and Bowyer 1994, 1998). Within population variation in size and physical condition likely would result from environmental heterogeneity (Miquelle *et al.* 1992) among home ranges in individual moose. Finally, there may be genetic differences among females that predispose some neonates to low weight. Additionally, compensatory responses may still occur beyond the age of moose that we sampled (Sand *et al.* 1995). Although our data did not explain why young moose failed to exhibit compensatory growth, the relationship between birth weight and future survival and productivity among moose warrants further study, as do the mechanisms underpinning compensatory growth in young ungulates. We acknowledge additional samples over a longer time frame and from a wider geographic range are necessary to achieve this result.

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