TRAIN MOOSE-KILL IN ALASKA: CHARACTERISTICS AND RELATIONSHIP WITH SNOWPACK DEPTH AND MOOSE DISTRIBUTION IN LOWER SUSITNA VALLEY

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ABSTRACT: Trends in moose (*Alces alces*) mortality (n = 3,054) due to train collisions along 756 km of railway in Alaska from 1963-90 are presented. Annual (May-April) mortality ranged from 9 to 725 moose. Winter (November-April) mortality varied from 7 to 705 moose, with more than 73% occurring from January through March. Mortality was greatest in sections of the railway transecting winter range. During the 1989-90 winter, 50 % (352 moose) of the train moose-kills occurred in a 64 km section of railway (8.5% of the railway length) in the lower Susitna Valley. There was a positive correlation among snowpack depth and train moose-kill, and moose numbers on winter range for the years when I studied the relationship. There was an inverse relationship between snowpack depth and moose density in alpine habitat, and between alpine density and train moose-kill for the years the relationship was studied. There was a relationship between the timing of deep snow and timing of moose occurrence on winter range, and timing of train moose-kill in two winters with greatly dissimilar patterns of snow accumulation. My results emphasize the importance of understanding moose movements in assessing and resolving the train-moose problem. Findings also identify the importance of alpine postrut concentration areas as a component of moose habitat.

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The Alaska railway passes through moose habitat in a 756 km route from Fairbanks, an interior location, to Seward, a marine port in south-central Alaska. Large numbers of moose are killed in train collisions during winter at specific locations in years with deep snow (Chatelain 1951, Rausch 1958). Losses of moose to train collisions are economically costly and socially unacceptable (Rausch 1958, Child 1983). The Alaska Railroad Corporation (ARC) and the Alaska Department of Fish and Game seek to mitigate train-moose conflicts. A first step in resolving the train-moose conflict is defining and understanding the nature of the problem.

The purpose of my study was to: (1) consolidate significant information on the train moose-kill, (2) describe characteristics of the train moose-kill and (3) explore relationships between snowpack depth, train moose-kill and moose distribution.

STUDY AREA

Railway

The Alaska Railroad railway goes between Seward (milemark = 0), a marine port on the east coast of the Kenai Peninsula in south-central Alaska, and Fairbanks (milemark = 470), a major city in the interior of the state (Fig. 1). The 756 km railway, passes through cities, towns, rural settlements, and vast expanses of unsettled land. The route traverses a variety of habitats including: coastal spruce-hemlock forests, closed spruce-hardwood forests, open low-growing spruce forests, shrub thickets and treeless bogs (Viereck and Little 1972). Elevation of the route changes from sea level in Seward to a high point of 700 m in Broad Pass (milemark = 297), on the south side of the Alaska Mountain Range, to 130 m at Fairbanks. The Alaska Mountain Range divides Alaska into interior and south-central geographical regions. In south-central Alaska, about 160 km of the railway runs near major lowland river drainages, extensive active floodplains and large tracts of unmaintained old homestead land clearings. Forest vegetation along the route in the lower Susitna Valley include mixtures of old growth white spruce (*Picea glauca*), black spruce (*Picea mariana*), paper birch (*Betula papyrifera*), aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*) and black cottonwood (*Populus trichocarpa*). Willows (*Salix* spp.), alders (*Alnus* spp.) and young deciduous tree species are particularly common at lower elevations in river drainages and in active floodplains. Early successional deciduous species dominate landscapes in settlements, unmaintained homesteads and the railway corridor where the ground surface has been disturbed by man. Willows and young deciduous tree species are preferred winter moose browse in south-central Alaska (Spencer and Chatelain 1953). Consequently, in winter, large numbers of migratory moose concentrate in locations along the railway in south-central Alaska where local conditions favor growth of early successional deciduous browse species.

Regional Conditions in Lower Susitna Valley

Winter climate in the lower Susitna Valley region is more variable and inclement away from the maritime influence of Cook Inlet and at higher elevations. Mean monthly temperatures vary from about 16 C in July to -13 C in January; maximum and minimum temperatures of 25 and -35 C are common. Total annual precipitation varies from about 40 cm in the south to over 86 cm in the north and west.

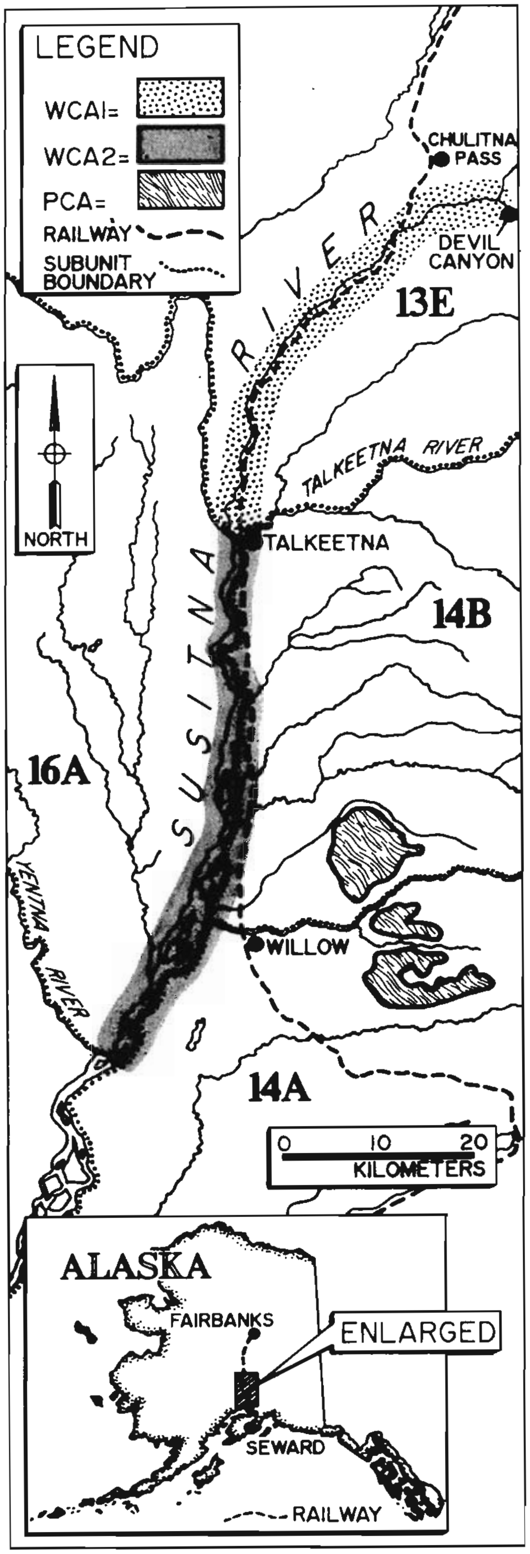

Fig. 1. Location of the 756 km railway between Seward (milemark 0) and Fairbanks (milemark 470) and the lower Susitna Valley study area in Alaska, showing game management subunits (14A, 14B, 16A and 13E), winter concentration areas (WCA1 and WCA2) and postrut concentration areas (PCA). Talkeetna and Willow were where snowpack depth was measured.

Snow accumulation varies with location, elevation, and site characteristics. Maximum snow depth can vary from <20 cm in the south to >200 cm in the north and west. Snow depth is generally deeper at higher elevations. Strong northerly winds often redistribute snow in exposed alpine sites and open floodplains. Snow accumulation in river channels varies depending on where and when ice forms over open water. Avalanches redistribute snow that accumulates on steep slopes.

Elevations within the region range from sea level to rugged mountain peaks well above 1500 m. Moose seldom use areas above 1100 m. Dominant habitat and canopy types in the region are characterized as: (1) floodplains dominated by willows, alders and poplars; (2) lowlands dominated by a mixture of wet bogs and closed or open mixed conifer-deciduous forests of paper birch, white spruce, black spruce, aspen; (3) mid-elevations dominated by mixed or pure stands of aspen, paper birch and white spruce; (4) higher elevations dominated by alder, willow, and birch shrub thickets (*Betula spp.*) or grasslands (*Calamagrostis spp.*); and (5) alpine tundras dominated by sedge (*Carex spp.*), ericaceous shrubs, prostrate willows, and dwarf herbs (Viereck and Little 1972).

METHODS

Train Moose-Kills

The ARC provided location and date for each moose-killed by the train on the railway between Seward and Fairbanks from October, 1963 through April, 1990. Accuracy in reporting train moose-kills in Alaska has greatly improved since 1980. Before which, numbers of were underreported (Rausch 1958). Data on train moose-kills before 1980 probably reflected month-to-month and year-to-year variations. Train moose-kill data for milemarks 0 to 470 were tabulated by year, season, month and location.

Train moose-kills were clustered in the section of the railway in the lower Susitna Valley. I explored relationships between snowpack depth, train moose-kill and moose distribution in a 145 km section of railway in the lower Susitna Valley from milemark 185 to 275. The high kill section of railway was divided into 2 segments. The train moose-kill on the segment extending from milemark 225 near Talkeetna to milemark 275 near Chulitna Pass was compared to moose counts in WCA1 and snowpack depth at Talkeetna. The train moose-kill on the segment extending from milemark 185 near Willow to milemark 225 was compared to moose counts in PCA and snowpack depth at Willow. The train moose-kill on the segment extending from milemark 185 to 275 was compared to moose counts in WCA1 + WCA2 and snowpack depth at Talkeetna.

Aerial Surveys

Numbers of moose were counted on aerial surveys in postrut concentration areas (postrut areas) and winter range in the lower Susitna Valley (Fig. 1). Survey areas were selected near railway sections with a high moose-kill.

Postrut areas (PCA) were located in the western foothills of the Talkeetna Mountains in Alaska Game Management Subunits 14A and 14B. This 240 km^2 area ranging in elevation from 600 to 1,200 m included 3 neighboring parcels of alpine habitat separated by lower elevation forested river drainages. This survey area was situated about 7 km east of the railway. In certain winters, moose were not found at higher elevations in the survey area. The area included portions of Bald Mountain Ridge, Moss Mountain and Willow Mountain.

Moose on winter range were surveyed in 2 areas of the Susitna River floodplain. One area was in Subunit 13E (WCA1); the other was in Subunit 16A (WCA2). The survey area in Subunit 13E was in the Susitna River floodplain between the Talkeetna River and Devil Canyon. This area encompassed 80 km of floodplain habitat ranging in elevation from 100 m at the Talkeetna River to 300 m at Devil

Canyon. Here, the floodplain was mostly <0.5 km wide with a scattering of islands. The railway from milemark 225-263 was mostly within 0.5 km of this survey area.

The survey area in Subunit 16A was located in the Susitna River floodplain between the Talkeetna River and the Yentna River. This area encompassed about 95 km of floodplain habitat ranging in elevation from 15 m at the Yentna River to 100 m at the Talkeetna River. In the survey area, the Susitna River floodplain was frequently >3 km wide where the river braids extensively around many small and large islands. The railway from milemark 185 to 225 was mostly within 2 km of this area.

Aerial surveys were conducted in winter, when snowcover was sufficient to observe moose, at 2- to 3-week intervals weather permitting. Surveys were conducted in WCA1 in 1981-85, WCA2 in 1982-84 and PCA in 1985-90. Survey flights were flown in Piper PA-18 aircraft at a search intensity of about 2.3 min per km^2. Low vegetative cover and good snow conditions in survey areas led to very high observability of moose.

Snowpack Depth

Snow depth data were obtained from Alaska Climatological Data Reports, U.S. Department of Commerce, NOAA, National Environmental Satellite, Data and Information Service, National Climate Data Center, Asheville, North Carolina. Snow depth data from Talkeetna were used as an index of snowpack depth in WCA1 and along the railway segment from milemark 225 to 275 in 1981-85, in WCA1+WCA2 and along the railway segment from milemark 185 to 275 in 1982-84, and along the railway segments from milemark 185 to 275 and milemark 225 to 275 in 1985-90. Snow depth data from Willow were used as an index of snowpack depth in PCA in 1985-90 and along the railway segment from milemark 185 to 225 in 1981-90. I presented the maximum snow depth recorded in each of 3, 10-day intervals (DIs) (1-10, 11-20 and 21-31 days) for each month. There were 21, DIs from October through April.

Snowpack depth was compared in relation to snowpack depth = 40 cm. Onset of fall-winter migrations of moose in Sweden (Sandegren *et al.* 1985) and Alaska (Van Ballenburghe 1977) were linked to snowpack depth of 42 and 40 cm, respectively.

Relationship Between Snowpack Depth, Moose Distribution and Train Moose-kill

To explore the relationship between snowpack depth, moose numbers on winter range, and train moose-kills, I used the Pearson correlation coefficient (Snedecor and Cochran 1980) to compare: (1) the maximum snowpack depth at Talkeetna (MSD-T) with the maximum number of moose counted in WCA1 (MMC-W) in 1981-85; (2) the MMC-W with the number of train moose-kills between milemarks 225 and 275 (TMK-T) in 1981-85; (3) the MSD-T with the TMK-T in 1981-85; and (4) the MSD-T with the TMK-T in 1981-90. Statistical significance was set at the 0.05 alpha level for all analyses in this papter.

To explore relationship between snowpack depth, moose numbers on winter range, and train moose-kills in 2 winters (1982-84) that differed greatly in the timing of snow accumulation, I used the Pearson correlation coefficient to compare: (1) the number of moose counted in WCA1 + WCA2 in each month (averaged by the number of counts per month) (AMC) with the number of train moose-kills between milemarks 185 and 275 in each month from November through March in the 1982-84 winters and (2) the AMC with the monthly maximum snowpack depth from November through March in the 1982-84 winters. I used a Chi-square analysis to compare the monthly number of train moose-kills between milemarks 185 and 275 from November through April in the winters, 1982-84. I used a Chi-square analysis with a Yates correction factor to compare the number of DIs with maximum snowpack depth <40 cm, and >40 cm in the 1982-83 and 1983-84 winters.

To explore the relationship between snowpack depth, moose numbers in postrut concentration areas and train moose-kills I used the Pearson correlation coefficient to compare: (1) the number of the DI when snowpack exceeded 40 cm at Willow (MIS-W) with the number of the DI when moose numbers in the PCA decreased by >75% in 1985-90; (2) the MIS-W with the number of train-moose kills between milemarks 185 and 225 (TMK-W) in 1985-90; (3) the number of the DI when moose numbers in the PCA decreased by >75% with the TMK-W in 1985-90; and (4) the maximum snowpack depth at Willow with the TMK-W in 1981-90.

RESULTS

Characteristics of the Train Moose-Kill

The ARC documented mortality of 3054 moose in train collisions in 756 km of railway between Seward and Fairbanks from May 1963 through April 1990. Numbers of train moose-kills ranged from 9 to 725 annually, May-April (Fig. 2). Numbers of train moose-kills ranged from 7 to 705 in winter. More than 93% of the train moose-kills were between Nov through Apr; 73.3% were in Jan through Mar (Fig. 3). Although only 3.5% and 4.4% of the annual train moose-kill occurred in November or April, it was 2.5-3.1 times greater than in any month from May through October.

In the 4 winters with the largest reported number of train moose-kills (1984-85 and 1987-90), kill locations were clusted in in Subunits 14A, 14B and 13E (Fig. 4). Kills were particularly numerous along a 193 km section of railway between milemarks 160 and 280 in the lower Susitna Valley. Other sections of the railway had few or no moose killed by trains. During the winters of 1984-85, and 1987-90, 204, 178, 88 and 352 moose were killed along a 64 km section of railway between milemarks 185 and 225. During these winters, 55, 56, 35 and 50 percent of the train moose-kills, respectively, occurred along 8.5

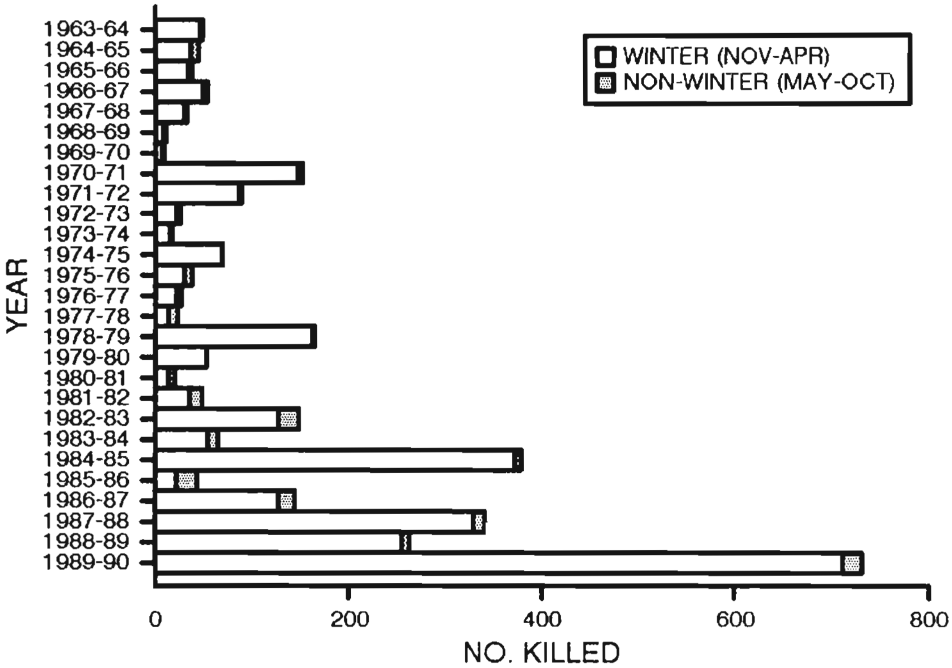

Fig. 2. Annual numbers of moose killed in train collisions May-April (n = 3054) and numbers killed in winter, November-April (n = 2851) and non-winter May-October (n = 203) in Alaska, 1963-90.

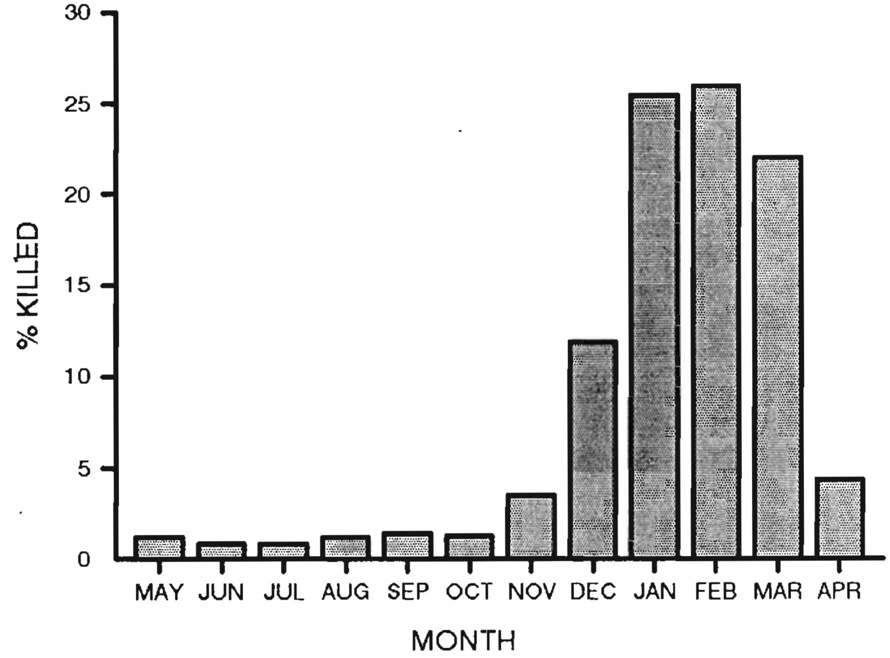

Fig. 3. Distribution of train moose-kills (n = 3054) by month in Alaska, 1963-90.

percent (64 km) of the railway.

Snowpack Depth, Moose Counts in Winter Concentration Areas, and Train Moose-Kills

Snowpack depth at Talkeetna, numbers of moose in winter concentration areas and numbers of train moose-kills varied greatly during 4 winters, 1981-85 (Fig. 5). Peak snowpack at Talkeetna, varied from 46 to 157 cm during these 4 winters. Snowpack generally increased from October through January, peaking in February or mid-March, and melting in late April. Thirty-four moose surveys were completed in WCA1 between November, 1981 and April, 1985, whereas 16 surveys were completed in WCA2 between November, 1982 and February, 1984. Thirty-seven surveys were conducted in PCA between October 1985 and March 1990.

The greatest number of moose counted in WCA1, in 34 surveys ranged from 36 to 132 during the 4 winters, 1981-85 (Fig. 5). Maximum numbers of moose counted was positively correlated with maximum snowpack depth during years 1981-85 (r=0.976,P=0.024, n=4). Thus the magnitude of moose meovement to winter range was related to snowpack depth.The fewest number of moose counted before and after the winter peak was 7 and 4, respectively. Moose numbers increased during November and December, peaking in January to mid-February, and then decreasing to low levels in March to mid-April. Numbers of train moose-kills between railway milemarks 225 and 275 ranged from 0-87 during the winters of 1981-85. There was a high non-significant positive correlation between train moose-kills and maximum moose counts during the winters 1981-85 (r=0.887,P=0.113, n=4). Train moose-kills were high when moose concentrated in winter areas near the railways.

Number of train moose-kills (1984-85) and the peak moose count was greatest when snowpack depth was greatest (Fig. 5). Train moose-kills (1981-82) and peak moose count was lowest when snowpack depth was lowest. There was a high non-significant positive correlation between greatest snowpack depth and train moose-kills during the 1981-85 win-

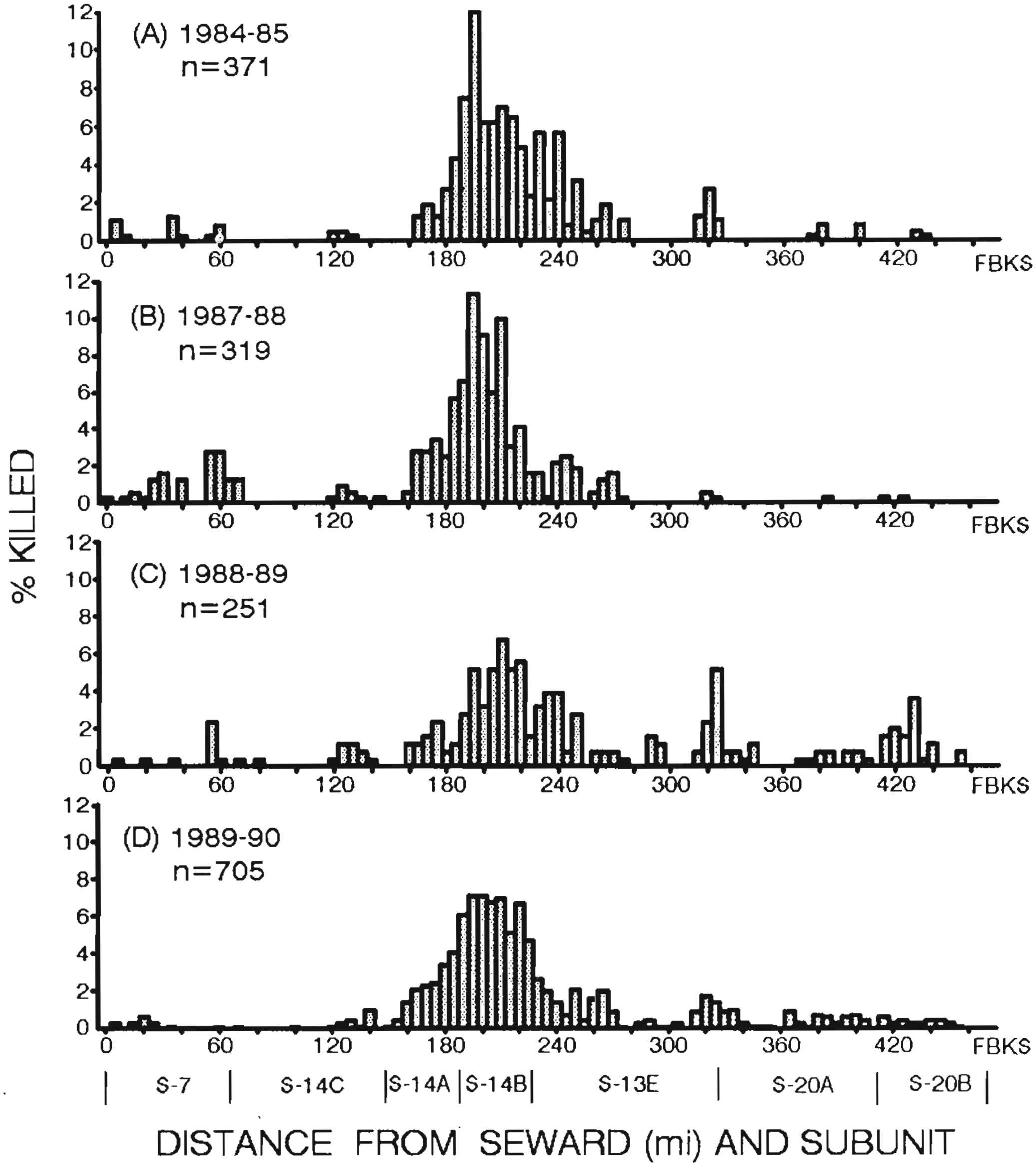

Fig. 4. Distribution of train moose-kills during winter, for 8-km sections along the railway from Seward (mi 0) to Fairbanks (mi 470), Alaska, during years, 1984, and 1987-89. Vertical lines below x-axis indicate milemark locations of Game Management Subunit (S-) boundaries. FBKS=Fairbanks.

ters (r=0.901,P=0.099,n=4). However, when the database was expanded including data from the 1985-90 winters, there was a significant positive correlation between snowpack depth and train moose-kills (r=0.962, P=0.0001, n=9). The train moose-kill was high when deep snow forced moose to migrate to winter concentration areas. Snowpack depth was bimodal in 1981-82, 1982-83 and 1984-85 (Fig. 5). Moose numbers in the WCA varied with this bimodal trend in snowpack depth (Fig. 5).

Snowpack depth, moose counts, and train moose-kills peaked earlier in 1982-83 than 1983-84 (Fig. 6). Snowpack depth increased from 23 to 81 cm between October and mid-January in 1982-83. During 1982-83, snowpack depth exceeded 40 cm by late Oc-

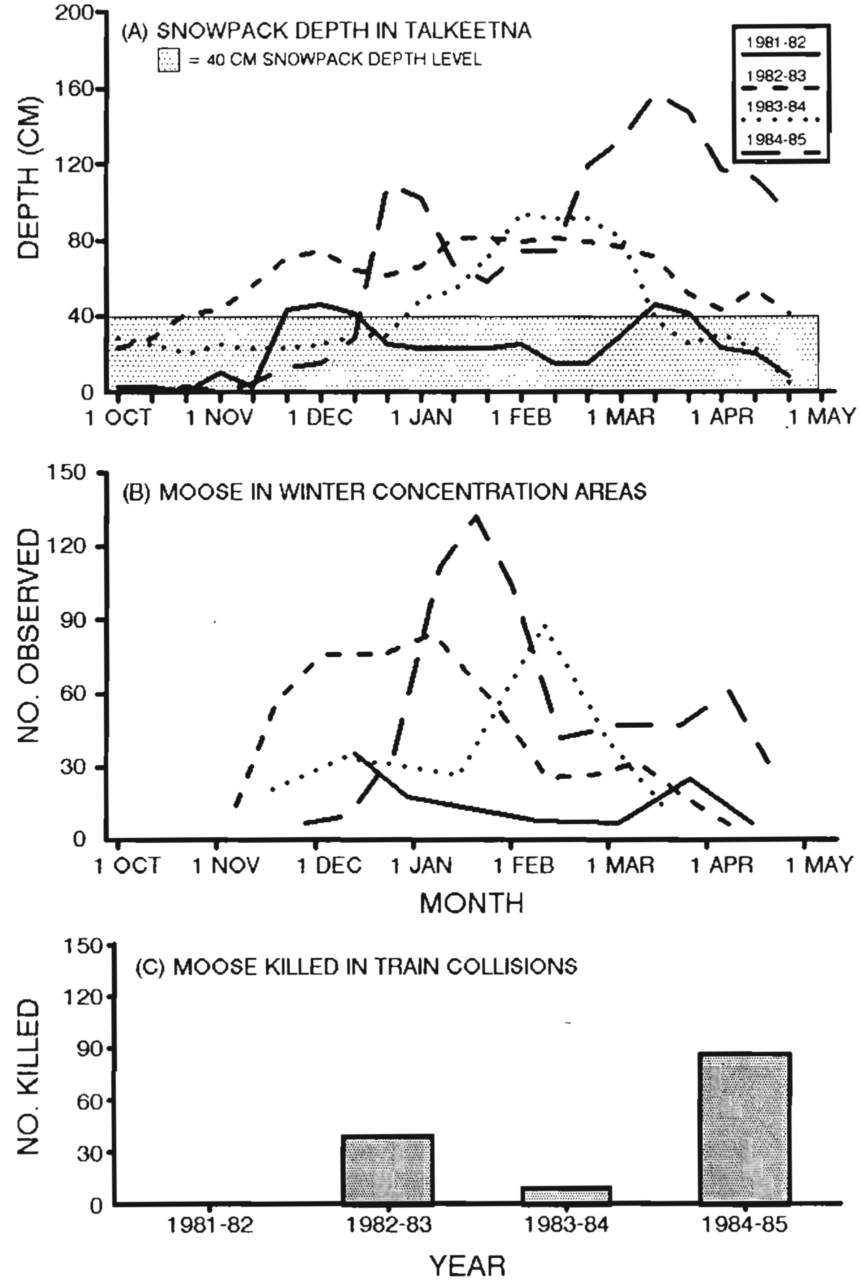

Fig. 5. Trimonthly maximum snowpack depth at Talkeetna (A), numbers of moose counted on aerial surveys in lowland winter concentration areas in the Susitna River floodplain between the Talkeetna River and Devil Canyon (B), and numbers of train moose-kills between railway milemarks 225 and 275, November-April (C), 1981-85, south-central Alaska. In other studies, onset of moose fall-winter migration coincided with snowpack depth = 40 cm.

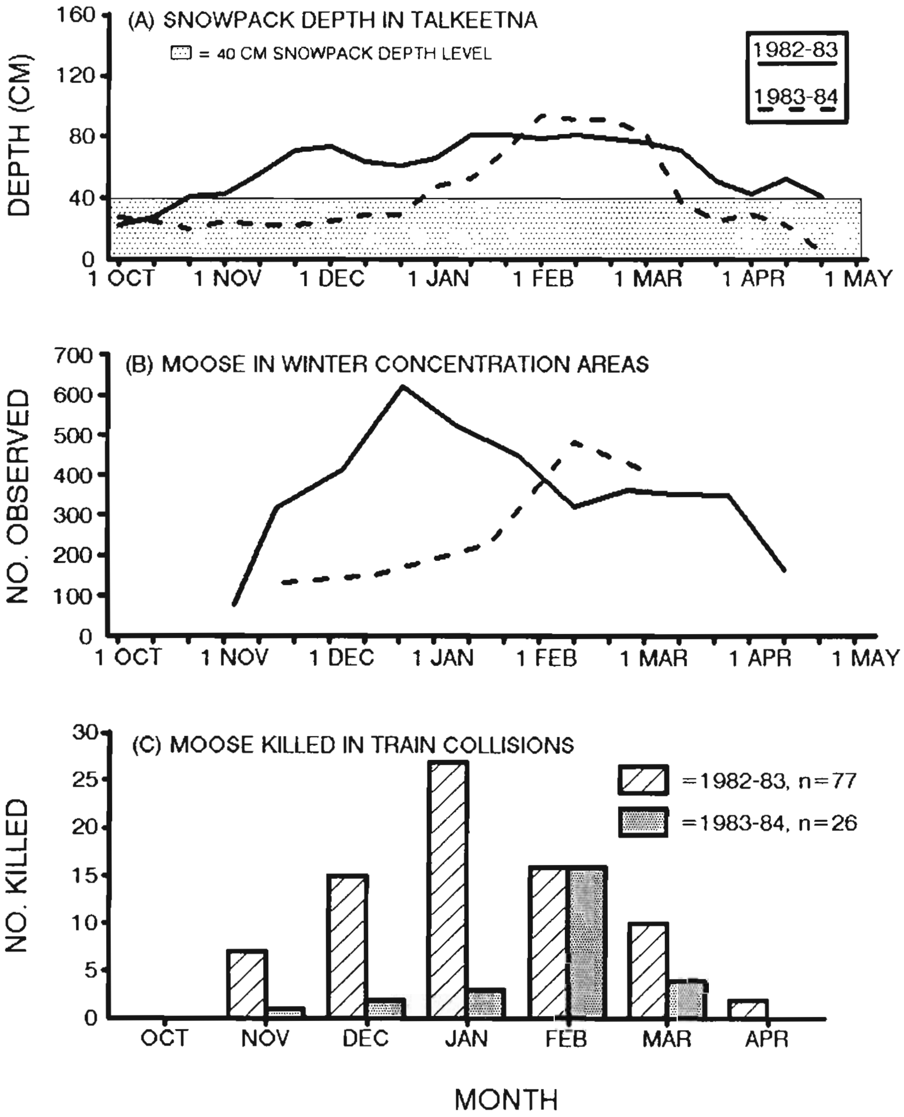

Fig. 6. Trimonthly maximum snowpack depth at Talkeetna (A), numbers of moose counted on aerial surveys in lowland winter concentration areas in the Susitna floodplain between the Yentna River and the Talkeetna River (B), and monthly number of train moose-kills between railway milemarks 185 and 275, October-April (C), 1982-84, south-central Alaska. In other studies,onset of moose fall-winter migration coincided with snowpack depth = 40 cm.

tober. In the 1983-84 winter, snowpack depth ranged from 5 to 94 cm. Snowpack depth exceeded 40 cm in early January, and peaked at 94 cm in early February. Snowpack depth exceeded 40 cm earlier and was >40 cm for a longer time in 1982-83 than 1983-84 ($X^2$12.22,df=1,P=0.005). Trends in numbers of moose counted in WCA1 + WCA2 differed between 1982-83 and 1983-84 (Fig. 6B). In 1982-83, numbers of moose ranged from 78 to 622 and peaked in late December, 1982. In 1983-84, numbers of moose ranged from 132 to 481, and peaked in early February. Monthly numbers of moose counted (AMC) were correlated with monthly maximum snowpack depth during November through March (r=0.764, P=0.016,n=9). Monthly numbers of train moose-kills were different between the 1982-83 and 1983-84 winters (Fig. 6) (X^2=17.17,df=5, P=0.0042). In 1982-83, train moose-kills peaked in January and 64 percent occurred before February. In 1983-84, train moose-kills peaked in February and 78 percent occurred after January. Monthly numbers of train-moose-kills were positively correlated with monthly numbers of moose counted (AMC) (r=0.815, P=0.008,n=9). The timing of snowpack accumulation influenced the timing of moose movements to winter concentration areas, and the timing of train moose kills.

Snowpack Depth, Moose Counts in Postrut Concentration Areas, and Train Moose-Kills

Snowpack depth at Willow, numbers of moose in postrut areas and numbers of train moose-kills varied among years 1985-90 (Fig. 7). Peak snowpack depth ranged from 43 to 234 cm. The greatest numbers of moose counted ranged from 626 to 938 moose, whereas the fewest number of moose counted before and after a winter peak was 42 and 12 moose, respectively. Numbers of moose counted in postrut concentration areas generally increased during October, peaked between late October and early December, and decreased from late December and mid-April.

In winter 1985-86, numbers of moose in postrut areas decreased by less than 50 percent between the peak count in early December and a count in late March. Snowpack depth first exceeded 40 cm in late March. In 1989-90, numbers of moose decreased precipitously in late October and early November, when 1989-90, snowpack depth first exceeded 40 cm in late October. Few moose were counted in late December, 1990, the year snowpack depth was greatest. During the winter of 1986-87, numbers of moose declined in December; snowpack exceeded 40 cm in early January. In the winters of 1987-89, moose numbers declined in mid-November to mid-December; snowpack depth exceeded 40 cm in late November.

The number of the DI when snowpack exceeded 40 cm was correlated positively with the number of the DI when numbers of moose counted in the PCA decreased to <75% of the peak count during the years 1985-90 (r=0.928, P=0.023,n=5). Moose dispersed from postrut concentration areas when snowpack exceeded 40 cm.

Numbers of train moose-kills between milemarks 185 and 225 ranged from 4 to 352 for the 1985-90 winters. Numbers of train moose-kills in winter were lowest in 1985-86, highest in 1989-90, and intermediate in 1986-89. Kills varied among the 3 winters with intermediate numbers of train moose-kills. Train moose-kills were twice as common in 1987-88 than 1988-89, and 2.4 times more numerous in 1988-89 than 1986-87. In 1986-87, snowpack depth exceeded 40 cm in early January, whereas in 1987-89 it exceeded 40 cm in late November. Snowpack depth in 1987-88 exceeded snowpack depth 1988-89 from mid-December through April. The numbers of the DI when snowpack exceeded 40 cm was not significantly correlated with the number of moose-kills 1985-90 (r=-0.793, P=0.109,n=5). The numbers of the DI when numbers of moose counted in the PCA were <75% of the peak count were not signficantly correlated with the numbers of moose-kills (r=-0.704,P=0.185,n=5). However, when the database was expanded including the 1981-85 winters, there was a significant positive correlation between maximum snowpack depth and train moose-kills ((r=0.815,P=0.007, n=9). The timing and depth of snow influenced dispersal of moose from postrut areas, and both correlated with train moose-kills. Maximum snowpack depth was an important factor influencing the number of train moose-kills. Perhaps, timing and magnitude of moose migrations from the PCA, which are influenced by snowpack depth, were weekly correlated with train moose-kills

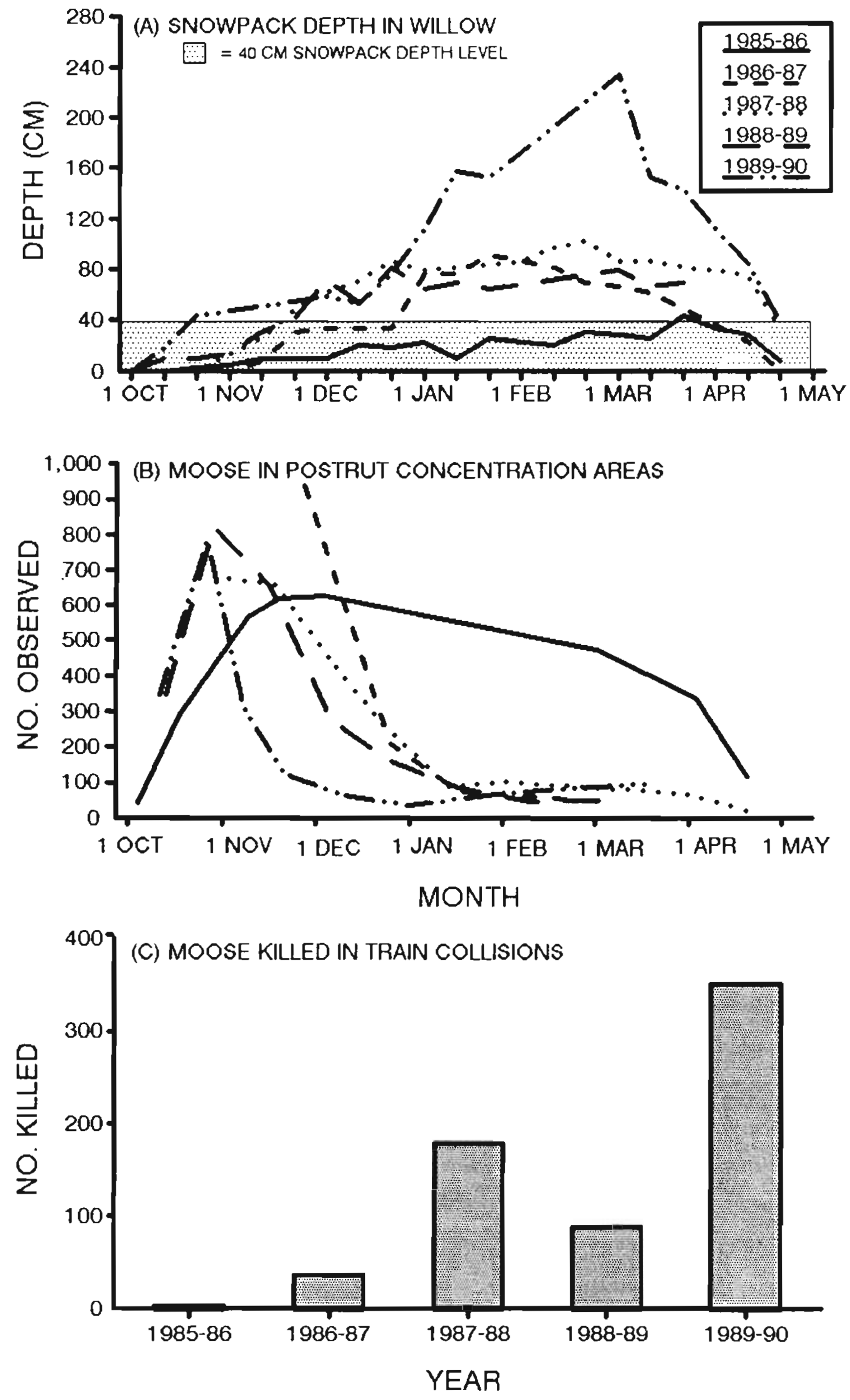

Fig. 7. Trimonthly maximum snowpack depth at Willow, numbers of moose counted on aerial surveys in alpine postrut concentration areas in the western foothills of the Talkeetna Mountains (B) and numbers of train moose-kills between railway milemarks 185 and 225, November-April (C), 1985-90, south-central Alaska. In other studies, onset of moose fall-winter migration coincided with snowpack depth = 40 cm.

because moose in the PCA migrate to winter range that is not near the railway.

DISCUSSION

A large number of moose were killed in train collisions in Alaska each year. This kill occurred mainly from November through April. Kills were clustered in certain segments of the railway, and more numerous in deep-snow winters. Kills were few in low-snow winters. These data agree with findings of others (Rausch 1958, Child 1983, Hatler 1983, Andersen *et al.* 1991). However, in southern Norway, <50% of the yearly train moose-kill occurred in winter (Jaren *et al.* 1991), and in Ontario and Manitoba, train-moose collisions were most frequent in June and July shortly after calving season (Child and Stuart 1987).

Train moose-kills increased when migratory moose moved to winter concentration areas near the railway. Kills were clustered in sections of the railway transecting migration routes and winter range. Kills were more numerous in deep-snow winters than in low-snow winters. In deep-snow winters, most moose in alpine postrut concentration areas dispersed to lowland winter range near the railway. In low-snow winters, many moose stayed in alpine habitat. The peak in train moose-kills occurred earlier in winter in an early-snow winter than in a late-snow winter because most moose migrated to winter range in response to snow accumulation. These findings were consistent with findings previously reported (Rausch 1958, Coady 1974, Van Ballenburghe 1977, Thompson *et al.* 1981, Child 1983, Sandegren *et al.* 1985). Although train moose-kills were numerous in deep-snow winters when large numbers of moose were near the railway, the additional affect of plowed snow along the railway likely affected behavior of moose increasing their vulnerability to train collisions (Rausch 1958, Child 1983, Hatler 1983, Andersen *et al.* 1991).

Loss of large numbers of moose in train collisions can have considerable consequences on management of local moose populations (Rausch 1958, Child 1983). More than 350 moose were killed in train collisions in Subunit 14B in the winter of 1989-90. However, in addition to moose resident in Subunit 14B, migratory moose from 2 neighboring Subunits were vulnerable to train collisions in Subunit 14B (R. Modafferi pers. comm.). Consequently, losses must be allocated among moose populations in 3 Subunits, and managers must understand movements of moose in the railway.

Plans to mitigate or resolve problems of train-moose collisions frequently include measures to manage habitat and moose populations along railways (Rausch 1958, Child 1983, Jaren *et al.* 1991). One option is to decrease numbers of moose near the railway. Forage along railways can be eliminated so moose are not attracted to the rail corridor. Habitat away from railways can be managed to attract moose and keep them distant from the rail corridor. Winter harvest quotas can be established near the railway. Fall harvest quotas can be increased in these Subunits overlapping the railway. However, findings in this study and another (R. Modafferi pers. comm.) suggest that these measures must be implemented at certain times and places to affect target moose populations.

In some moose management jurisdictions, railway corporations fail to provide wildlife managers with an accurate account of train moose-kills (Rausch 1958, Child and Stuart 1987). In Alaska, railway managers have cooperated with wildlife managers in collecting information on train-moose conflicts and in testing measures to help resolve the problem.

My findings indicate that moose distribution and numbers on winter range were related to snow accumulation throughout the winter. These findings agree with observations of Edwards and Ritcey (1956) who noted that snow depth was a major factor influencing timing and extent of moose migrations and yearly differences in moose distribution. Van Ballenburghe (1977) found that snow conditions caused moose to break from traditional migratory patterns during a seasonal cycle. Crete (1980) showed that moose did not winter in the same forest stands during consecutive winters; snow conditions were not assessed. Modafferi (pers. comm.) indicated that some individual radio-marked moose in the lower Susitna Valley migrated differently and were located in different areas in a low-snow winter versus a series of average- to deep-snow winters. In contrast, Sweanor and Sandegren (1987) reported that moose fall-winter migration patterns were consistent each year. However, in all years of their study, snow depth exceeded 40 cm, the threshold snow depth that initiated onset of migrations in moose (Sandegren *et al.* 1985). In this study, timing, magnitude and extent of moose migrations were correlated with snowpack depth. My findings suggested that not all moose migrated in response to the same threshold of snowpack depth, and that snow depth influenced the final destination of migrations of moose.

There is considerable information on movements of moose to winter concentration areas and the importance of winter concentration areas to moose (Stevens 1970, Telfer 1970, Brassard *et al.* 1974, Coady 1974, LeResche 1974, Peek 1974, Van Ballenburghe 1977, Crete and Jordan 1982, Sandegen *et al.* 1985, Lavsund 1987, Danell and Bergstrom 1989, Hundertmark *et al.* 1990). There is less data available on movements of moose to postrut concentration areas and the importance of postrut areas in moose ecology (LeResche 1972, Lynch 1975, Thompson *et al.* 1981). Like winter concentration areas, importance of postrut concentration areas, is suggested by the traditional use by large numbers of moose. Moose left surrounding habitats to move to these postrut areas in early winter before deep snowpack forced them to move to winter range (Coady 1974, Telfer 1978). Thompson et al. (1981) suggested that quantity and quality of browse in moose early winter concentration areas was superior to browse in surrounding habitats. Weight and body condition of moose entering winter determines survival and influences productivity the following spring (Saether 1987, Schwartz *et al.* 1988). During the postrut period, moose increase food intake (Schwartz *et al.* 1984) and gain weight (Schwartz *et al.* 1987). Quality of range in these postrut concentration areas likely influenced moose movements to them.

My observations indicated moose winter range has two components, alpine postrut concentration areas and lowland winter concentration areas. Snowpack depth affected timing, duration and magnitude of moose use of each component. When deep snowpack occurred early, moose dispersed from postrut areas in November to winter ranges. During winters with low snowpack many moose stayed in alpine postrut concentration areas. This extended use of postrut areas reduced the impact of browsing on forage in lowland winter concentration areas. These findings suggest that moose postrut concentration areas were an intergral component of moose habitat that deserve protection and further study.

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