single hypothetical development scenario presented in the 1987 Final Legislative Environmental Impact Statement (Clough et al. 1987). The scenarios in Tussing and Haley (1999) are based on the most recent estimates of the distribution and quantity of oil reserves within the 1002 Area (U.S. Geological Survey 2001).

This protocol assumed oil field design similar to the Kuparuk and Milne Point petroleum development areas within the scenario boundaries. The modeling exercise could be used to assess the potential effects of additional development scenarios that are not presented in Tussing and Haley (1999) or Clough et al. (1987).

Central Arctic herd parturient females actually separated their concentrated calving areas from development infrastructure by about 7-8 km (Wolfe 2000). We used a conservative displacement of 4 km based on observations by Cameron et al. (1992) of increased caribou density from 4 km outward beyond roads and pipelines. Calving sites and the entire annual calving grounds were displaced along with the concentrated calving areas.

Our protocol stated that a concentrated calving area could not be moved onto the Beaufort Sea. We made no changes in shape of the concentrated calving areas or annual calving grounds. As a result of these shifts, relatively small portions of the peripheral, low-density calving areas were occasionally moved onto the Beaufort Sea along with some associated calving sites. We treated these ocean sites as missing data when assessing the potential effects of displacement on calf survival.

Modeled displacement for the Porcupine caribou herd was to the east and south, parallel to the Beaufort Sea coastline, because that is the direction of the herd's migratory approach to the annual calving grounds in spring. Displacement of the developed-zone concentrated calving areas of the Central Arctic herd has been primarily to the south, the direction of approach to that calving ground from winter range.

Our protocol minimized displacement of the Porcupine caribou herd calving grounds into the foothills and mountain zone. This tended to keep the annual calving grounds on the coastal plain in the best remaining foraging habitats. In some cases, observed concentrated calving areas (e.g., in 1988, 2000, and 2001) did not overlap the boundaries of any of the hypothetical development scenarios, and in those cases the annual calving ground was not displaced.

Once the concentrated calving areas and associated annual calving grounds and calving sites were displaced, the forage during peak lactation (NDVI_621) within the displaced annual calving ground was re-inventoried, the median was recalculated, and the proportion of calves born in the low predation risk zone (coastal plain) was recalculated.

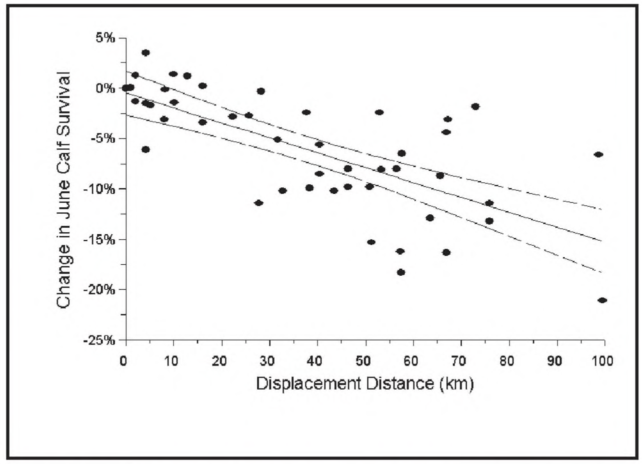

Figure 3.28. Estimated change in calf survival during June for the Porcupine caribou herd, 1985-2001, as a function of the distance of displacement of the annual calving ground and associated concentrated calving area and calving sites. Upper and lower dashed lines indicate 95% confidence intervals on the mean effect.

Then the empirical model was again used to predict calf survival for the displaced calving ground. The difference between the calf survival estimate for the displaced and observed calving ground was calculated and a dataset of 16 displacement distances and associated changes in calf survival was generated for analysis.

The model showed a significant ($r^2 = 0.47$, $P < 0.001$) inverse relationship between displacement distance and predicted change in calf survival (Fig. 3.28).

The simulations indicated that a substantial reduction in calf survival during June would be expected under full development of the 1002 Area. Eighty-two percent of observed calving distributions would have been displaced and the average distance of these displacements would have been 63 km (range 16-99 km). This would have yielded a net average effective displacement of 52 km and an expected mean reduction in calf survival of 8.2% (SE = 0.7%).

It is remotely conceivable that calving caribou of the Porcupine caribou herd could select habitats that yielded equivalent forage and predation risk after displacement. Forage for lactating females of the Central Arctic herd, however, declined as the concentrated calving area in the developed zone shifted to the south-southwest (Wolfe 2000). This suggests that such compensatory habitat use by the Porcupine caribou herd would be unlikely if their calving grounds were displaced by oil development.

Because there was no empirical basis for changing the shape of the observed calving distributions, it was impossible to estimate the magnitude of the effect of considering the peripheral calving areas and calving sites as missing data when they were displaced onto the ocean. The effect was expected to be small. Arbitrarily assigning calving sites that were displaced onto the ocean back onto the coastal plain and making no other adjustments would have increased displaced calf survival by only about 0.6% on average. This probably constituted the maximum possible effect of treating areas and calving sites that were displaced to the Beaufort Sea as missing data.

tochastic simulation modeling (Walsh et al. 1995) indicated that a 4.6% reduction in Porcupine caribou herd calf survival during June, all else held equal, would have been sufficient to halt growth of the Porcupine caribou herd during the best conditions observed to date. A 10-km average displacement in our simulations would have been sufficient to bring the upper confidence interval on the mean effect below a 0% predicted change in calf survival (Fig. 3.28). A mean displacement of 27 km in our modeled predictions would have been sufficient to reach the threshold of 4.6% mean reduction in calf survival sufficient to halt growth of the Porcupine caribou herd under best observed growth conditions to date. This latter level of displacement could occur well before full development of the 1002 Area.

The estimated effect of displacement of the Porcupine caribou herd on calf survival during June was conservative for several reasons. First, we used the conservative estimate of a 4 km displacement of concentrated calving areas from infrastructure (Cameron et al. 1992) versus 2-8 km (Wolfe 2000). Second, we displaced the concentrated calving areas parallel to the Beaufort Sea coastline thus maintaining calving distributions on the best remaining coastal plain habitat and minimizing displacement into the foothills where predation would be expected to increase calf mortality. Finally, relatively low density calving was allowed to overlap developed areas, as has been observed for the adjacent Central Arctic herd (Wolfe 2000, Lawhead and Prichard 2001).

Because the assumptions were conservative, the results were conservative. Substantial (10 to 27 km) displacement of concentrated calving areas and associated annual calving grounds and calving sites of the Porcupine caribou herd is likely to negatively affect calf survival during June. At the upper end of this range of displacement (27 km), recovery of the herd from the current decline (Fig. 3.8) would be unlikely. These conclusions are consistent with those found in the 1987 Final Legislative Environmental Impact Statement (Clough et al. 1987).

The Porcupine caribou herd has demonstrated substantial natural variability in size and demography (Figs. 3.5, 3.8, 3.10*a-c*). Because development of the 1002 Area would take time, any effects on the herd's performance may take decades to detect. Reduced calf survival may slow the rate of increase during positive phases of the growth curve of the herd and increase the rate of decline during the negative phases of the herd's growth curve. The period of natural cycles in herd size may increase and the amplitude of herd size may be affected.

The best empirical tool available for detecting potential effects of development is the modeled relationship between calf survival and forage for females during peak lactation demand (NDVI_621) within the extent of calving (Fig. 3.26). This model is independent of actual annual calving ground location and encompasses a near full cycle of herd size as well as substantial variation in hemispheric weather patterns (Fig. 3.5) and variation in calving ground location (Fig. 3.13).

With industrial development, if observed calf survival falls below the lower 95% confidence limit on the predicted observations from this model (Fig. 3.26), or if a parallel pattern of calf survival yields a significantly lower intercept term, then an effect of development on calf survival would be indicated.

Individual observations that fall below the lower confidence limit and which can be satisfactorily explained by exceptional environmental characteristics (e.g., carry-over effects of near-catastrophic conditions in 1992 to 1993 after eruption of Mount Pinatubo) (Fig. 3.26) need not be considered evidence for effects of development on calf survival. A pattern of observed calf survival below the lower confidence limit would be cause for concern.

tatistical methods for making these types of decisions are currently in development (Rexstad and Debevec 2001). This assessment will require continued intensive calving ground surveys and calf survival estimates.

Conclusions

Our research has shown that the Porcupine caribou herd has significant annual variance in calving ground location (Fig. 3.13), faces annual variance in habitat conditions, selects areas with abundant high quality forage for calving, has increased survival of calves born in the concentrated calving areas, and shows a correlation between calf survival and both forage for females during peak lactation and predation risk in the annual calving grounds. All this implies that unrestricted access to annual calving grounds and concentrated calving areas maximized performance of lactating Porcupine caribou herd females and their calves. Because the Porcupine caribou herd has shown limited capacity for growth, free access to calving ground habitats may have compensated for less than optimal wintering habitats.

Location of the concentrated calving areas during the past 19 years (1983-2001) is the best estimate of the area that has provided the highest quality calving habitat for females and their calves. Calf survival within the aggregate extent of concentrated calving areas has been higher than for calves born in areas never used as a concentrated calving area (83.8% vs.73.9%, respectively,