Exploring Correspondences among Bathurst Caribou Demographic Variables, Summer Range Anomalies and Climate during 1985-2011

Wenjun Chen[1], Lori White[1], Jan Z. Adamczewski[2], Bruno Croft[2], Donald E. Russell[3], Anne Gunn[4], Jody Snortland Pellissey[5], Karin Clark[5], Kerri Garner[6], Ian Olthof[1], Risam Latifovic[1], Greg L. Finstad[7], and Robert G. White[8]

Canada Centre for Remote Sensing, Natural Resources Canada; [2]Environment and Natural Resources, GNWT; [3]Yukon College; [4]Salt Spring Island, [5]Wek'èezhìi Renewable Resources Board, Yellowknife, NWT; [6]Tlicho Government, Behchoko, NT, [7]School of Natural Resources and Agricultural Sciences, University of Alaska; [8]Institute of Arctic Biology, University of Alaska

Objectives

In this study, we aim to: (1) investigate potential correspondence between summer range forage availability and quality anomalies derived from satellite remote sensing and caribou demographic variables (e.g., calf:cow ratios, survival rates, start date of peak calving), and (2) assess impacts of climate variability on these anomalies.

Data sources

The start date of peak calving for the Bathurst caribou herd during 1985-2011 was complied from Sutherland and Gunn (1996) and Gunn and Poole (2009), calf:cow ratios at peak calving, fall calf:cow ratios, late-winter calf:cow ratios, calf and cows survival rates during 1985-2011 were compiled from Boulanger et al. (2011) and Adamczewski et al. (2012). Climate data at the Lupin station are used to represent the Bathurst summer range. Anomalies of the Bathurst summer range were derived from satellite remote sensing and field measurement data (see companion poster).

Methods

The principle of limiting factors suggests that, at any given time in a particular ecosystem, productivity is constrained by a single, metabolically essential factor that is present in least supply relative to the potential biological demand. Following the principle of limiting factors, we developed relationships between the minimum values of summer range mean anomalies (SRMA) and caribou demographic variables. Considering that there were many other factors that might influence these demographic variables as well (in other words, even if the summer range conditions were favourable, calf:cow ratios or survival rates could still be reduced due to other factors), we use the upper-envelop line to quantify the impact of summer range anomalies.

To understand the impact of climate on these summer range anomalies, we examined the relationships between summer range anomalies and climate variables (e.g., maximum temperature and the Keetch-Byram Drought Index (KBDI)).

Result (1): Correspondences between demographic variables & summer range anomalies

We found significant correlation between the start date of peak calving and the start date of growing season (SOS) of the lichen-low vegetation class, which dominates the calving ground (Fig. 1).

If peak calving started before SOS in year *i*-1, cows on the calving ground would have no green leaves to forage. The lack of green leaves on the calving ground during the peak calving period appeared to have a negative impact on cows, and apparently the affected cows were able to remember these conditions the following year. Consequently, the start date of peak calving in the next year might be delayed. For example, year 2004 was found to have the latest SOS on June 20 or DOY 172, and the peak calving started on June 8 (i.e., DOY 160). Correspondingly, the start date of peak calving was the latest in 2005 on June 14 (or DOY 165). For years in which peak calving began before SOS in year *i*-1, the SOS of year *i*-1 can explain 92% of the variation in the start date of peak calving in year i, with $R^2 = 0.92$, $n = 7$, and p-value of 0.0006. On the other hand, when SOS in *i*-1 is earlier than the start date of peak calving in year *i-1*, the peak calving time in year *i* appeared to not be affected and maintained at an almost fixed date of DOY 159 (i.e., June 7 or 8 depending on calendar years). Together, these two lines can explain 66% of the variations in the start of peak calving dates for the Bathurst caribou herd, with $R^2 = 0.66$, $n = 17$, p-value = 6.78×10^{-5}, and standard estimation error = 1.15 d.

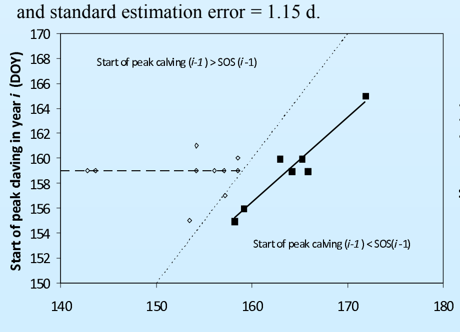

Figure 1. Relationship between the start date of peak calving and the start date of growing season of the lichen low vegetation class in previous year.

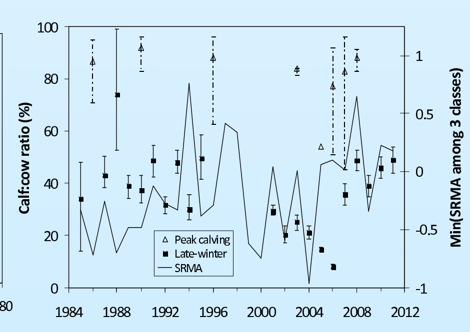

Figure 2. Inter-annual variations in late-winter calf:cow ratios, calf:cow ratios at peak calving, and min(SRMA among 3 classes) from 1985-2011.

One of the most important caribou demographic variables is the late-winter calf:cow ratio, a measure of caribou net productivity, usually measured during March-April for the Bathurst caribou herd. The late-winter calf:cow ratios increased from 35% in 1985 to upwards 50% in the 1990's, declined sharply to only 8% in 2006, and then recovered to upwards 50% during 2007-2011 (Fig. 2). Similar trends have been observed for the calf:cow ratios at peak calving (i.e., fecundity rate) and the fall calf:cow ratios (not shown), although with fewer observations.

From Figure 2, we found that these demographic trends appeared to be corresponding well with the minimum values of SRMA among the 3 land cover classes. The values of min(SRMA among the 3 classes) were about -0.7 in late 1980's, increased to > -0.3 in 1990's, declined to -0.96 in 2004, and then recovered to mostly > 0.

To further analyze the potential impact of summer range conditions on late-winter calf:cow ratios, in Figure 3 we plotted the late-winter calf:cow ratio in year *i* against the min(SRMA in years *i*-1 and *i*-2 among 3 classes). As a measure of net productivity, the late-winter calf:cow ratio combines the results of the birth rate of survival rates (= the calf:cow ratio at peak calving × the calf survival rate from peak calving in early June to late winter / the cow survival ratio during the same period). These calf and cow survival rates from peak calving to late winter in March-April were probably influenced by the summer range conditions in year *i*-1, while the calf:cow ratio at peak calving in year *i*-1 was likely affected by cow pregnancy rate and summer range conditions in year *i*-2. In addition, a later SOS in year *i*-2 might delay the start date of peak calving in year *i*-1, which in turn might affect the late-winter calf:cow ratio in year *i*. Overall, it is difficult to quantify the relative importance of SRMA in years *i*-1 and *i*-2 on the late-winter calf:cow ratios, we used the minimum SRMA among these two years and the 3 classes on the basis of limiting factor principle.

Because there were many other factors (e.g., winter range conditions, predators, harvest rate, diseases/parasites) could affect the late-winter calf:cow ratios, a reduced calf:cow ratio could occurred in a year with favourable summer range conditions. Therefore, the upper-envelop line of the late-winter calf:cow ratios against the min(SRMA in years *i*-1 and *i*-2 among the 3 classes) plot approximates the limiting effect of summer range conditions. Figure 3 shows that the late-winter calf:cow ratios should reach 50% when all conditions were favorable, and be reduced at a accelerated rate as the summer range conditions worsen in previous 2 years to 10% when min(MSRA in years *i*-1 and *i*-2 among the 3 classes) = -1. Values of late-winter claf:cow ratios below the line indicates likely influences of other factors.

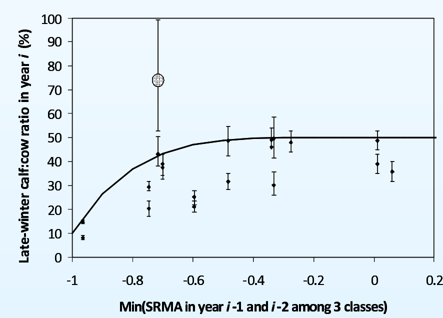

Figure 3. Impact of summer range mean anomalies on the Bathurst caribou late-winter claf:cow ratios during 1985-2011. The late-winter calf:cow ratio in 1988 is an outlier and thus excluded.

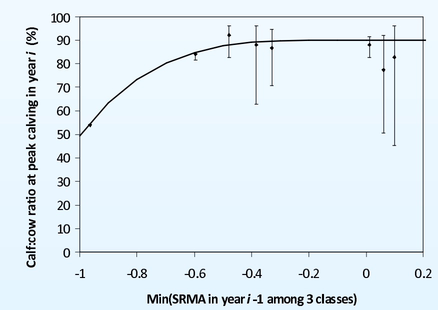

Figure 4. Impact of summer range mean anomalies on the Bathurst caribou calf:cow ratios at peak calving during 1985-2011.

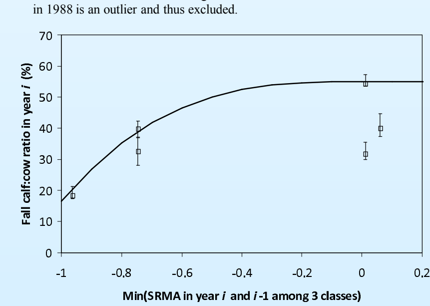

Figure 5. Impact of summer range mean anomalies on the Bathurst caribou fall calf:cow ratios during 1985-2011.

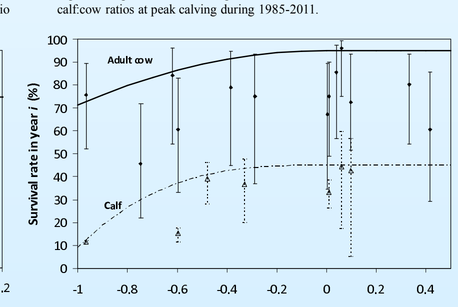

Figure 6. Impacts of summer range mean anomalies on the Bathurst caribou calf and cow survival rates during 1985-2011.

The late-winter calf:cow ratio of 0.74 in 1988 appears to be an outlier for the following reasons. First, it was 50% higher than the next highest value. No similar high values had been measured in all other 20 observations during 1985 and 2011. Secondly, in order to obtain such an extreme high late-winter calf:cow ratio, the calf survival rate would have to 0.67, calculated by assuming an average fecundity rate = 0.82 and adult cow survival rate = 0.74. This is much higher than any of 7 measured calf survival rates. The highest observed calf survival rate was 0.44 (Fig. 6). Therefore, we excluded the 1988's late-winter calf:cow ratio from the upper enveloping process. After excluding the outlier, the upper-envelop line of the late-winter calf:cow ratios against the min(SRMA in years *i*-1 and *i*-2 among 3 classes) plot is able to explain 54% of variations in late-winter calf:cow ratios (i.e., $R^2 = 0.54$, $n = 19$, and p-value = 0.0003).

Similar upper-envelop line may be defined as the impact of min(SRMA in year *i*-1 among 3 classes) on the claf:cow ratios at peak calving (Fig. 4). As the value of min(SRMA in year *i*-1 among 3 classes) declined from positive to -1, the calf:cow ratios at peak calving decreased from 90% to 50%. The upper-envelop line explains 83% of variations in the calf:cow ratios at peak calving (i.e., $R^2 = 0.83$, $n = 8$, and p-value = 0.0015).

The fall calf:cow ratios decreased from 55% to 18% as the value of min(SRMA in year *i*-1 among 3 classes) being reduced from positive to -1 (Fig. 5). The upper-envelop line of the fall calf:cow ratios against the min(SRMA in years *i* and *i*-1 among 3 classes) explains 55% of variations in fall calf:cow ratios (i.e., $R^2 = 0.55$, $n = 6$, and p-value = 0.09).

The adult cow survival rates were generally much higher than that of calf (Fig. 6), although both showing a decline trend with min(SRMA in year *i*-1 among 3 classes). As the value of min(SRMA in year *i*-1 among 3 classes) declined from positive to -1, the adult cow survival rates decreased from 95% to 70%, while the calf survival rate dramatically declined from 45% to 10%. The upper-envelop line of the adult cow survival rate against the min(SRMA in year *i*-1 among 3 classes) explains only 12% of variations in the adult cow survival rate, and is statistically insignificant, with $R^2 = 0.12$, $n = 13$, and p-value = 0.25. On the other hand, the upper-envelop line of the calf survival rate vs. min(SRMA in year *i*-1 among 3 classes) is able to explain 65% of variations in the adult cow survival rate, with $R^2 = 0.65$, $n = 7$, and p-value = 0.027. The faster and significant decline trend of calf survival rates suggests that poor summer range conditions might exert a larger influence on the calf survival rates than that of adult cow.

Result (2): Climate impacts on summer range anomalies

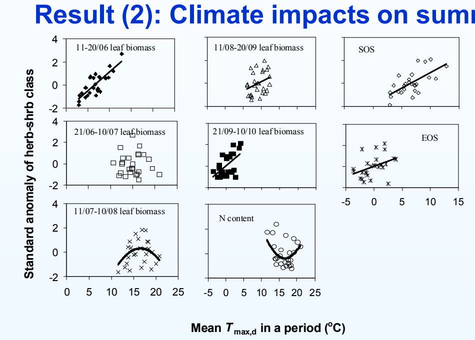

Figure 7. Relationships between Bathurst summer range anomalies and T_{max} from 1985-2011.

A non-linear relationship between mean daily max temperature (T_{max}) and leaf biomass was observed in mid-summer (11/07-10/08) for all 3 classes, with the optimal T_{max} = 16.5 °C (Fig. 7). For years with T_{max} > 16.5 °C, negative leaf biomass anomalies were detected during summer periods. For periods with T_{max} < 16.5 °C, significant linear relationships were found, especially just after snowmelt during 11-20/06 when water was not a limitation. A similar linear relationship were also found between anomaly of SOS (or EOS) and T_{max} during 11-20/06 (or 21/09-10/10). In 2004, the year with the lowest SRMA, we had the lowest 11-20/06 mean T_{max} at 2.9 °C (1985-2011 normal = 6.7°C), the 3rd lowest 11/08-20/09 mean T_{max} at 6.4 °C (1985-2011 normal = 8.9°C), & the 3rd lowest 21/09-10/10 mean T_{max} at -2.5 °C (1985-2011 normal=-0.2 °C).

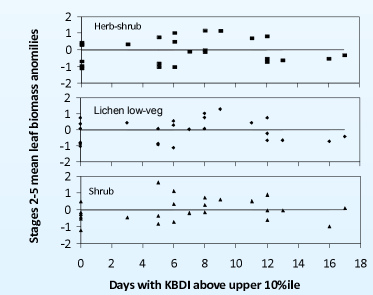

Figure 8. Relationships between 4-periods mean leaf biomass anomalies and days with KBDI above upper 10 percentile over the Bathurst summer range from 1985-2011.

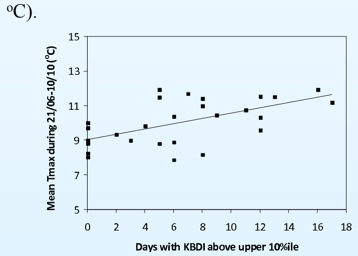

Figure 9. Relationships between days with KBDI above upper 10%ile and mean T_{max} from 21/06 to 10/10 at the Lupin climate station from 1985-2011.

Except 11-20/06, all other 4 periods were potentially subject to drought effect. We examined the relationship between the average of anomalies in leaf biomass over the 4 periods (21/06-10/10) and the number of days with KBDI above the upper 10 percentile. The 4-periods when mean leaf biomass anomalies increased as the days with KBDI above the upper 10%ile up until about 9 d, and then decreased for all 3 classes (Fig. 8). Year 2000 and 2011 had the highest days with KBDI above upper 10%ile (= 17 and 16), both of which resulted in negative 4-periods leaf biomass anomalies. The 2000 drought might be partially responsible for initiating the decline in calf:cow ratios and survival rates of the Bathurst caribou herd in the early 2000's.

At first glance, these results do not seem to be biophysically meaningful. They, however, can be explained. The effects of "drought" are twofold. The direct effect is soil moisture limitation, which reduces leaf biomass. The indirect and secondary effect is through temperature. On average over 1985-2011, there was a strong positive relationship between T_{max} and days with KBDI above 10%ile (Fig. 9). Consequently, the secondary effect of "drought" could increase leaf biomass when T_{max} < 16.5 °C , but reduce leaf biomass when T_{max} > 16.5 °C.

Conclusions

(1) The SOS in year *i*-1 can explain 92% of the variation in the start date of peak calving in year *i*, if peak calving in year *i*-1 was later than SOS.
(2) The minimum values of the summer range mean anomalies can explain a significant portion of the variation in calf:cow ratios at peak calving (83%), fall calf:cow ratios (55%), late-winter calf:cow ratios (54%), and calf survival rates (65%), but not in adult cow survival rates (only 11% and statistically not significant at the 90% confidence level.
(3) Climate impacts on the summer range anomalies were complex and non-linear.

Reference

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