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# A General Approach to Harvest Modeling for Barren-ground Caribou Herds in the NWT and Recommendations on Harvest Based on Herd Risk Status

John Boulanger
Integrated Ecological Research,
Nelson, BC

Jan Adamczewski
Environment and Natural Resources,
Government of Northwest Territories

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## ABSTRACT

Previous modeling of barren-ground caribou demographics and harvest for the Bathurst and Bluenose-East herds was carried out under a limited range of demographic scenarios to evaluate the likely consequences of varying levels and sex ratio of harvest. The modeling in this report was carried out to assess risk associated with harvest in a wider range of conditions, to generate more general results that could be applicable to multiple herds varying in size and trend. A deterministic model was used with a caribou herd of 100,000 with low, moderate and high calf productivity and low, moderate and high levels of adult survival. Harvest levels modeled ranged from 0-8,000, and sex ratio of the harvest varied from 0-100% cows. Time-steps of three and six years were used to match the frequency of recent Government of the Northwest Territories population surveys of most caribou herds. With low adult survival, herd trend is likely to be negative and a substantial harvest would increase the risk of greater decline. Herds with high survival and high calf productivity can tolerate substantial harvest levels. Power to detect declines within three years was limited to larger scale (>31%) declines in herd size. Bull-cow ratios were sensitive to male and female harvest levels with increases in bull-cow ratios when female harvest was higher. Case studies of the Bathurst and Bluenose-East herds using the most recent demographic information suggest that harvest should be very conservative, given herd size, trend and relatively low cow survival in these herds. Recommended harvest should be re-assessed frequently because a herd's productivity and survival rates can change quickly. Results of the harvest modeling were used to develop approaches to recommending harvest level and sex ratio based on herd risk status, including a simple rule of thumb approach.

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# INTRODUCTION

In the wake of declines in all barren-ground caribou herds monitored by the Government of the Northwest Territories (GNWT) in the early 2000s, harvest management was recommended by co-management boards and implemented for the Cape Bathurst, Bluenose-West and Bathurst herds (Adamczewski et al. 2009, Boulanger et al. 2011). Population modeling was carried out in 2009-2010 to assess acceptable hunter harvest (number and sex ratio) for the Bathurst herd compatible with providing the herd a strong opportunity to recover (see Boulanger and Adamczewski 2015 and Boulanger et al. 2011).

Long-term management planning for these herds, the Bluenose-East herd (e.g. ACCWM 2014), and for the Beverly and Qamanirijuaq herds is either completed or underway. Management recommendations for harvest for multiple herds at various population sizes and trends will be needed. The purpose of this paper is to demonstrate a modeling process that can be used to estimate the risk of harvest for a population based upon its relative size and trend. The modeling is intended to provide guidelines that could be used by co-management boards or governments to complement harvest management strategies developed through co-management processes. The modeling does not address harvest allocation. We also recognize that harvest recommendations and herd-based plans will reflect other criteria, knowledge and views, in addition to biological considerations.

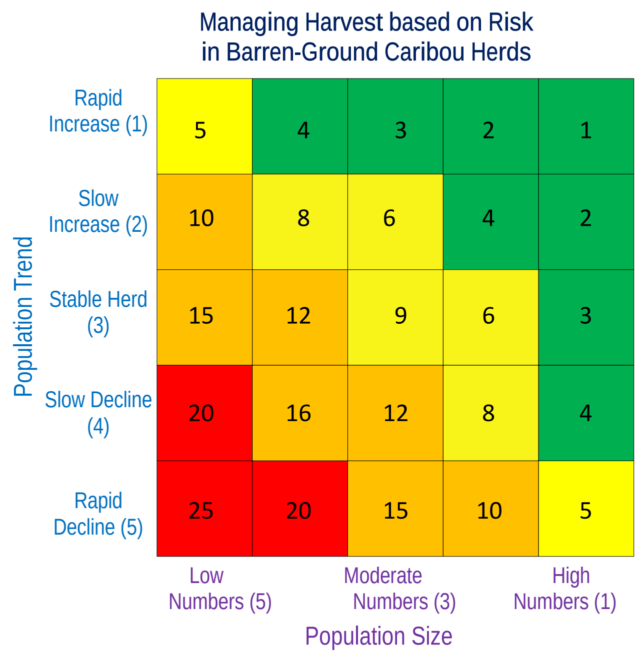



**Figure 1.** Relative levels of risk as a function of population trend and size.

It is important to remember that other factors that influence caribou, such as weather in all seasons, predation, and cumulative effects of development, will continue to affect each herd. In addition, barren-ground caribou herds have long been known to fluctuate widely in numbers over time (Zalatan et al. 2006, Bergerud et al. 2008). Caribou harvest management will need to be flexible and adaptive to shifting conditions for each herd.

# METHODS

The underlying model used for simulations was similar to the demographic model used for the Bathurst and Bluenose-East herds (Boulanger and Adamczewski 2015, Boulanger et al. 2011, Boulanger 2016 In Prep.). Because this was a deterministic model, no variation was simulated in model parameters.

This model attempts to define the relative risk to a herd of various harvest strategies as evaluated at three and six years. This approach is meant to emulate the management process where harvest levels are initially set based upon herd size with usually less knowledge about population trend. Therefore, managers often are faced with only knowing one of the axes in Figure 1 when setting harvest levels. However, if surveys are conducted at three year intervals then it should be possible to re-evaluate trend and population size. Therefore, simulations are tailored to ask what risk category a herd would be at three years after a harvest regime is imposed.

## Selection of Input Parameters

Parameters were selected to span the most commonly observed values in caribou herds. Model parameters were based upon ranges of adult survival (Figure 2) and levels of productivity (as indicated by calf-cow ratios) (Figure 3) observed for various caribou herds. Adult female survival is directly related to herd trend (Figure 2) so adult survival rates also dictated overall herd trend with smaller scale changes dictated by productivity levels.

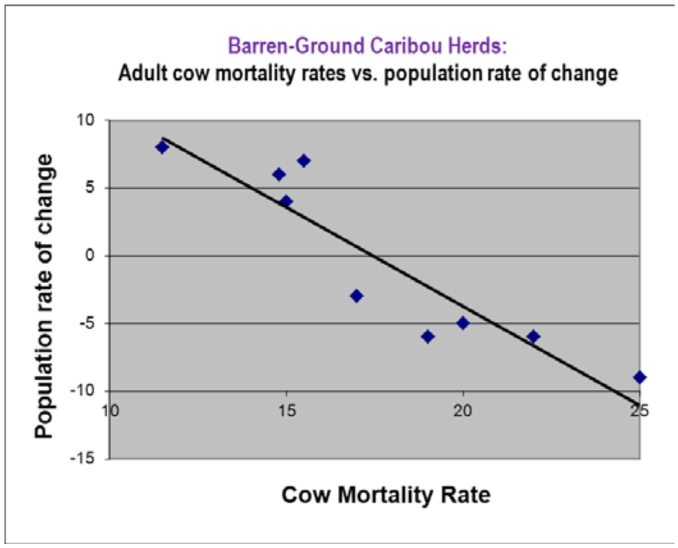



**Figure 2**. Empirical relationship between caribou adult cow survival rates and population rate of change (courtesy of Don Russell, coordinator, CARMA Network, personal communication).

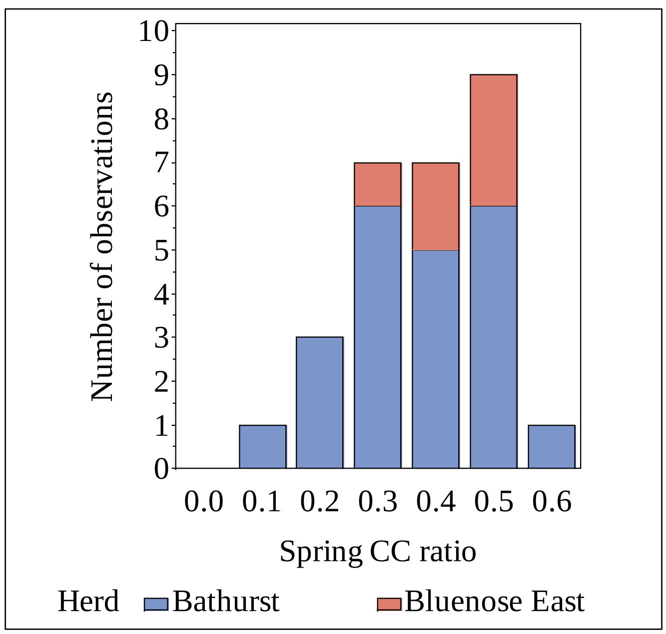



**Figure 3.** Ranges of spring (March-April) calf-cow ratios for the Bathurst herd (1985-2012) and Bluenose-East (2007-12) caribou herds.

Productivity was modeled as the product of calf survival and fecundity (the relative proportion of adult females that produce a calf each year). Productivity in this context would be the proportion of calves that survive their first year of life relative to the number of adult females that gave birth to calves on the calving ground in the previous year. The actual measure that is available for productivity is calf-cow ratios recorded in late winter at about ten months of age and therefore an initial step of modeling was to calibrate productivity values so that they spanned the observed range of calf cow ratios. This was done by adjusting calf survival values (which vary more than fecundity) to produce calf-cow ratios that ranged from 0.2-0.5 (Figure 3). We note that calf-cow ratios were relatively unaffected by adult female survival values (Figure 4), with a slight tendency for higher values if adult female survival was lower.

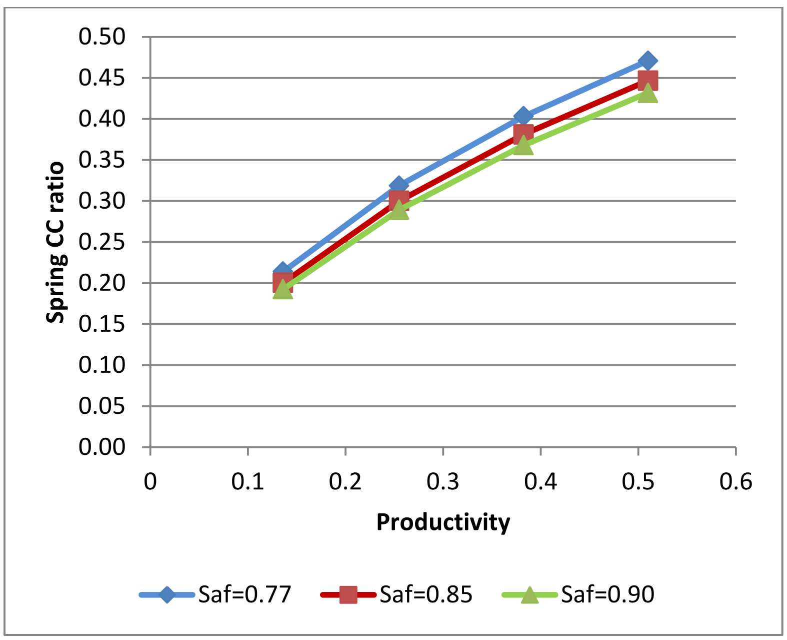



**Figure 4.** Productivity values with corresponding calf-cow ratios. Various values of adult survival (Saf) are given. Other parameters are listed in Table 1.

Other parameter values were based upon relationships from the OLS model analysis of the Bathurst herd (Boulanger et al. 2011) (Table 1). Namely, yearling survival was set equal to adult female survival and bull survival was assumed to be 80% of the value of adult female survival. The initial bull-cow ratio was set at 0.43 which was the average value of estimated bull-cow ratios for the Bathurst herd from 2004-12 (range=0.36-0.56) and the estimated value for the Bluenose-East herd in 2010. As discussed later, these assumptions should be re-considered for herds that have actual demographic parameter estimates since they assume demography that is similar to the Bathurst herd (a declining herd) and the Bluenose-East herd (the bull-cow ratio).

One point that is important to note is that productivity is partially influenced by adult female survival given that higher survival of adult females means that more calves will be produced in a given year. For example, for simulations the initial number of adult females (out of the herd size of 100,000) was 69,930. The actual number that produced calves was determined by the product of adult survival and fecundity. Thus higher adult survival values resulted in higher numbers of breeding females (Table 1).

**Table 1.** Initial parameterization of simulations. Productivity was the product of calf survival and fecundity. Initial breeding females was the product of initial cows (69,930 *adult survival* fecundity). Asymptotic λ values for females and calf cow ratios are also given.

| Survival Scenario | Productivity | Survival | | | | Fecundity | Initial | Female Trend | CC* ratios | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cow | Bull | Calf | Yearling | | Breed F N* | λ | Spring | Fall |
| **Low** | 0.14 | 0.77 | 0.62 | 0.16 | 0.77 | 0.85 | 45,769 | 0.83 | 0.21 | 0.40 |
| | 0.26 | 0.77 | 0.62 | 0.30 | 0.77 | 0.85 | 45,769 | 0.87 | 0.32 | 0.46 |
| | 0.38 | 0.77 | 0.62 | 0.45 | 0.77 | 0.85 | 45,769 | 0.90 | 0.40 | 0.50 |
| | 0.51 | 0.77 | 0.62 | 0.60 | 0.77 | 0.85 | 45,769 | 0.94 | 0.47 | 0.52 |
| **Moderate** | 0.14 | 0.85 | 0.68 | 0.16 | 0.85 | 0.85 | 50,524 | 0.91 | 0.20 | 0.38 |
| | 0.26 | 0.85 | 0.68 | 0.30 | 0.85 | 0.85 | 50,524 | 0.95 | 0.30 | 0.45 |
| | 0.38 | 0.85 | 0.68 | 0.45 | 0.85 | 0.85 | 50,524 | 0.99 | 0.38 | 0.49 |
| | 0.51 | 0.85 | 0.68 | 0.60 | 0.85 | 0.85 | 50,524 | 1.02 | 0.45 | 0.51 |
| **High** | 0.14 | 0.90 | 0.73 | 0.16 | 0.90 | 0.85 | 53,496 | 0.96 | 0.19 | 0.38 |
| | 0.26 | 0.90 | 0.73 | 0.30 | 0.90 | 0.85 | 53,496 | 1.00 | 0.29 | 0.44 |
| | 0.38 | 0.90 | 0.73 | 0.45 | 0.90 | 0.85 | 53,496 | 1.04 | 0.37 | 0.48 |
| | 0.51 | 0.90 | 0.73 | 0.60 | 0.90 | 0.85 | 53,496 | 1.08 | 0.43 | 0.51 |

*Breed F N = Breeding Female Number; CC = Calf: Cow

The combinations of productivity and adult survival resulted in asymptotic λ values for the female segment of the population ranging from 0.83-1.08 which corresponded to an annual 17% decrease up to an 8% increase respectively (Figure 5). At low cow survival rates (0.77), the expected population trend was negative at all levels of productivity.

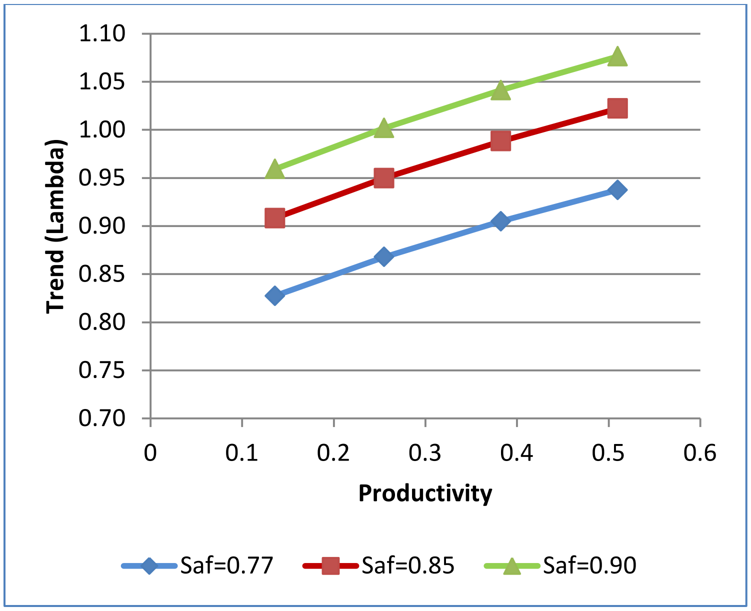



**Figure 5.** Trend in female population size as a function of productivity and adult female survival.

## Selection of Risk Thresholds

The next step in the modeling process was to assign simulation outcomes to risk categories for the herd as evaluated in three and six years. To do this, the relative risk zones in Figure 1 were assigned categories based on herd size and annual rate of population change. As with Figure 1, higher rates of decline were considered acceptable for larger herd sizes but as herd size decreased the risk of serious decline were considered less acceptable.

**Table 2.** Thresholds of risk as a function of trend and population size.

**Population Size (thousands)**

| **Lambda** | **% change** | **<30** | **30-60** | **60-90** | **90-120** | **>120** |
|---|---|---|---|---|---|---|
| >1.1 | >10% | 5 | 4 | 3 | 2 | 1 |
| 1.02-1.09 | 2-9% | 10 | 8 | 6 | 4 | 2 |
| 0.98-1.02 | -2 to +2% | 15 | 12 | 9 | 6 | 3 |
| 0.9-0.98 | -10 to -2 | 20 | 16 | 12 | 8 | 4 |
| <0.9 | <-10% | 25 | 20 | 15 | 10 | 5 |

In the context of Table 2, risk levels associated with green and yellow were considered acceptable, risk zones of orange were considered to be of concern, and risk zones of red and black as not acceptable (warranting strong consideration of harvest restriction).

## Case Studies for Bluenose-East and Bathurst Herds

The simulations conducted assumed a starting herd size of 100,000 caribou as a benchmark. We also ran a set of simulations that were tailored to the Bluenose-East and Bathurst herds to further illustrate the application of the generic harvest model across two different combinations of herd size and trend.

# RESULTS

The relative risk of various harvest strategies was evaluated graphically with harvest levels as the x-axis and percent cows as the y-axis at three years (Figure 6) and at six years (Figure 7). Figures 6 and 7 present a wide range of outcomes specific to combinations of cow survival rate, calf productivity, harvest levels and harvest sex ratio. These graphs can also be viewed in a simpler manner: graphs with substantial amounts of green and yellow represent situations with relatively little risk of significant decline, while graphs with substantial red or black represent situations with a high risk of serious decline.

Included were results with zero harvest which corresponded to the farthest left cells on each plot. The relative amount of harvest pressure increased with increasing x-axis values but also with increasing y-axis values since the harvest would include more females. When evaluated at three years, it can be seen that the highest risk categories corresponded to the low survival and low productivity (0.14-0.25); herds with these conditions would be declining with zero harvest. In most other scenarios risk was moderate to low. However, this result was potentially misleading since a decreasing population would only have three years to decrease therefore the longer-term risks of various harvest strategies may not be as evident. If the same simulations are evaluated at six years then risk levels become higher for all of the low survival scenarios, for the medium survival scenarios if productivity <0.25, and for the high survival scenarios if productivity ≤0.14) (Figure 7). This result highlights the need for frequent re-evaluation of harvest strategies at three year intervals especially if the initial harvest strategy places a herd into a higher risk category.

In general, the lowest risk situations were herds with high adult survival and high calf productivity; these herds could tolerate substantial harvest levels, including cow harvest. These conditions were last seen in the Northwest Territories caribou herds in the early 1980s. In herds with low adult survival, a declining trend was expected with no harvest, thus any significant harvest would increase the risk of rapid decline.

One question that would be related to adaptive management is whether the effects of different harvest strategies could be detected within three years. Power analyses (Figure 8) were also evaluated graphically to explore this question. In Figure 8, red or green cells indicate that a negative or positive change would be detected in breeding female estimates. It can be seen that decreases would be detectable for the low survival scenario regardless of harvest when productivity was low (<0.25) and at higher harvest levels when productivity was higher. Declines would only be detectable at higher harvest levels in the medium and high survival scenarios when productivity was low.

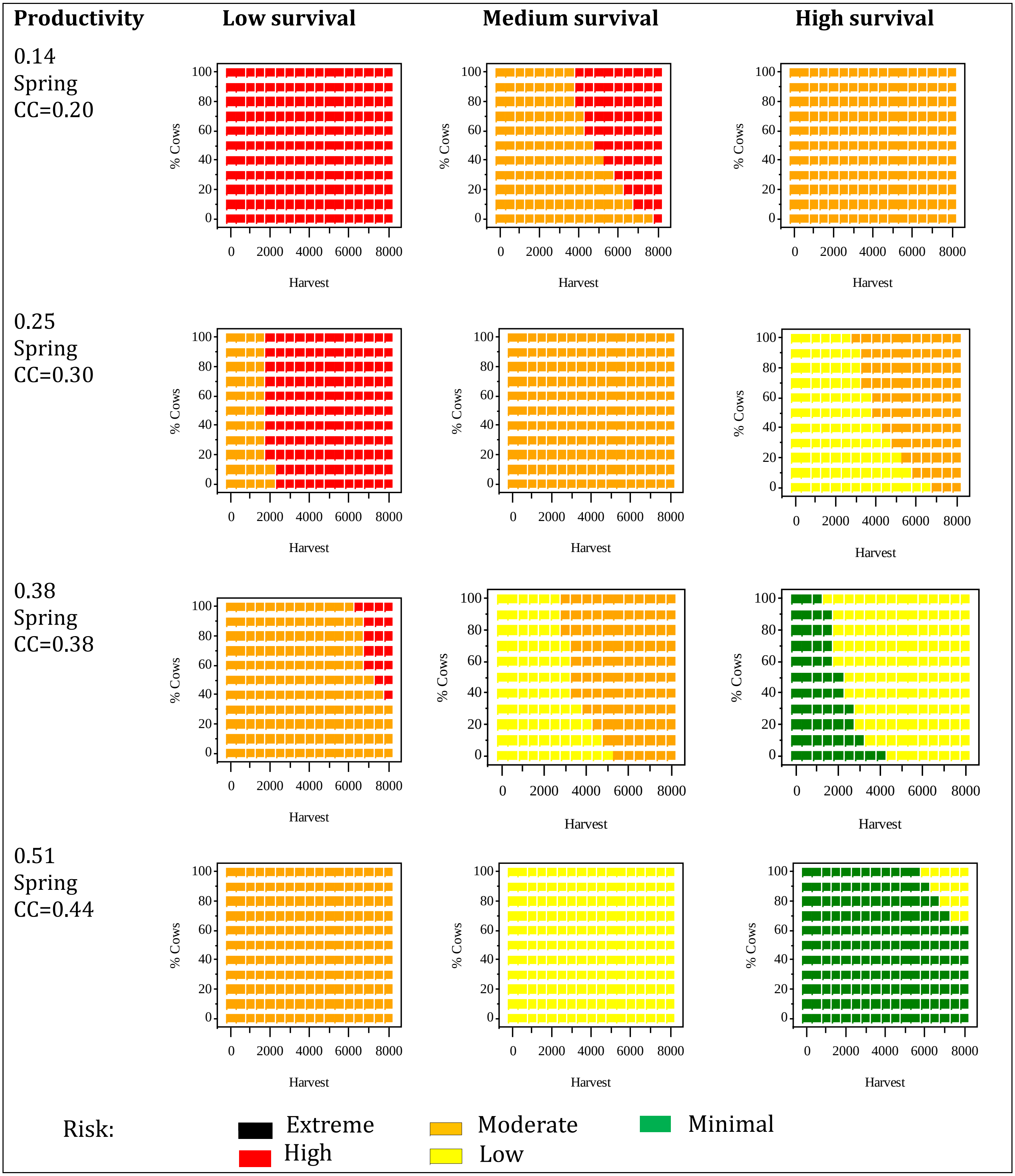



**Figure 6.** Relative risk of various harvest strategies when evaluated at three years. Risk categories are defined in Table 2.

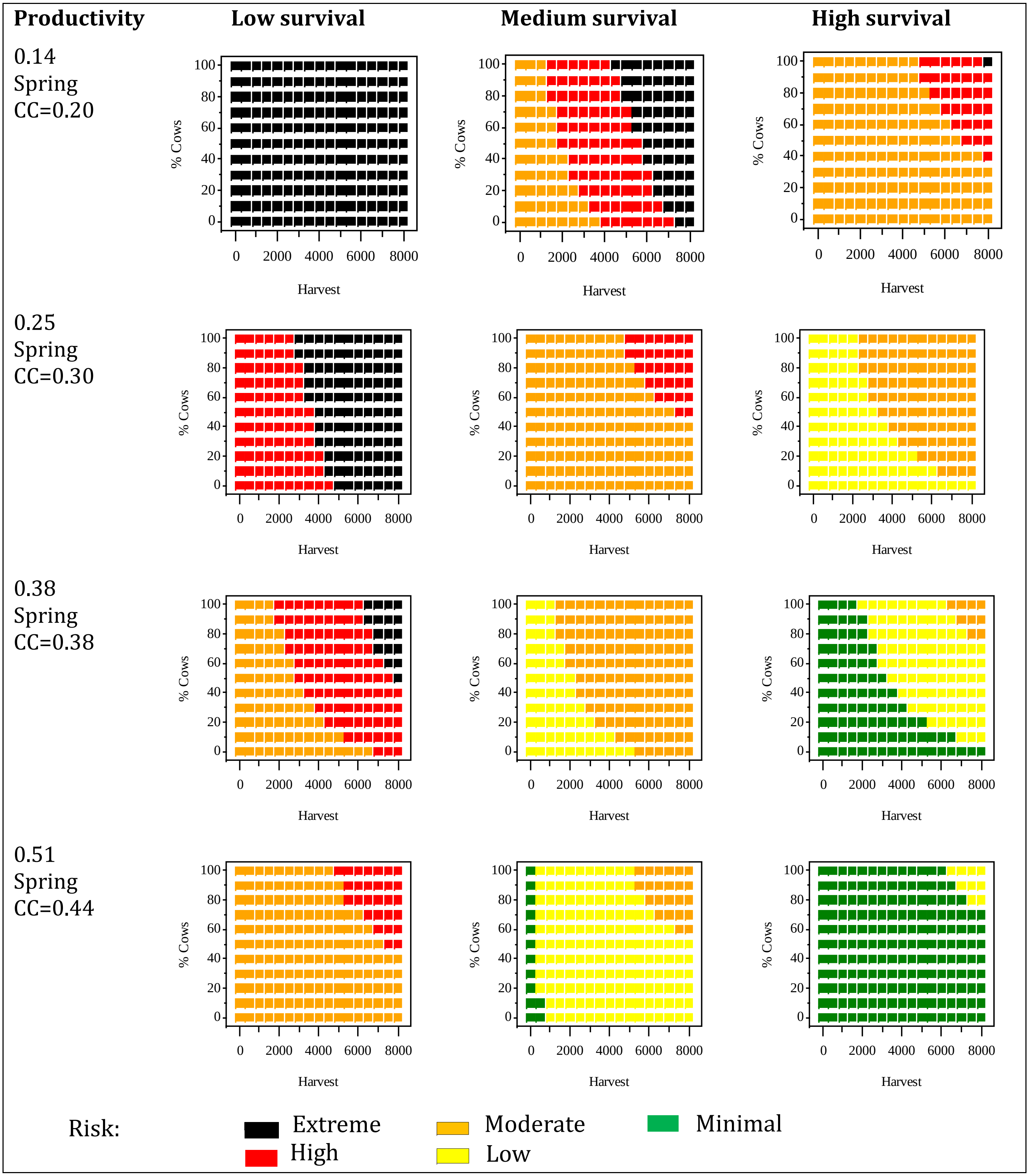



**Figure 7.** Relative risk of various harvest strategies when evaluated at six years. Risk categories are defined in Table 2.

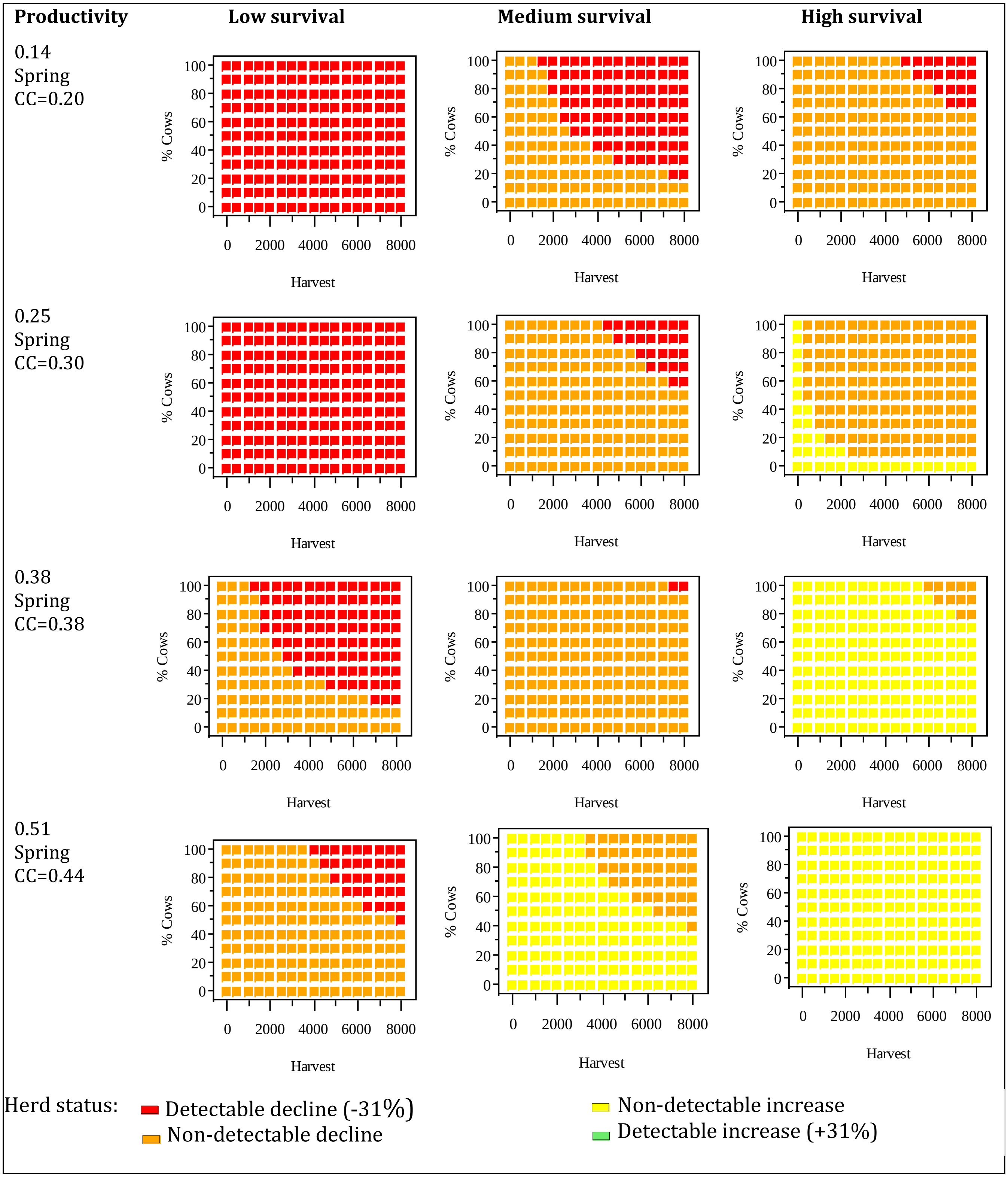



**Figure 8.** Power to detect change at three years based on various harvest levels. Red denotes that a negative trend was detected (at least 31% decline) whereas orange would be a non-detectable decline, yellow a non-detectable increase and green a detectable increase of at least 31%.

One important indicator of herd status is the bull-cow ratio which can signal a depletion of bulls when harvest is strongly bull-oriented. In general bull-cow ratios should remain high enough to ensure that breeding success is not reduced. However, naïve interpretation of bull-cow ratios can be misleading given that a ratio can also increase if the cow population size is decreasing relative to bulls (due to cow harvest or other factors). Figure 9 displays simulation results in terms of bull-cow ratios with higher risk indicated by red and black cells. Moderate and lower risks are indicated by orange and yellow whereas minimal risk (an increase in bull-cow ratio) is indicated by green. A grey cell indicates an increase in bull-cow ratio compared to the initial value that was partially due to a decrease in cow population size. In this case, an increasing bull-cow ratio would be misleading. From this it can be seen that higher bull harvest caused extreme risk (black cells) in scenarios where productivity is <=0.38. Grey areas (decreasing cows relative to males) could occur at higher harvest levels when the majority of the harvest is cows. In general, if productivity is above 0.38 then moderate harvest of bulls results in acceptable risk in terms of bull-cow ratios.

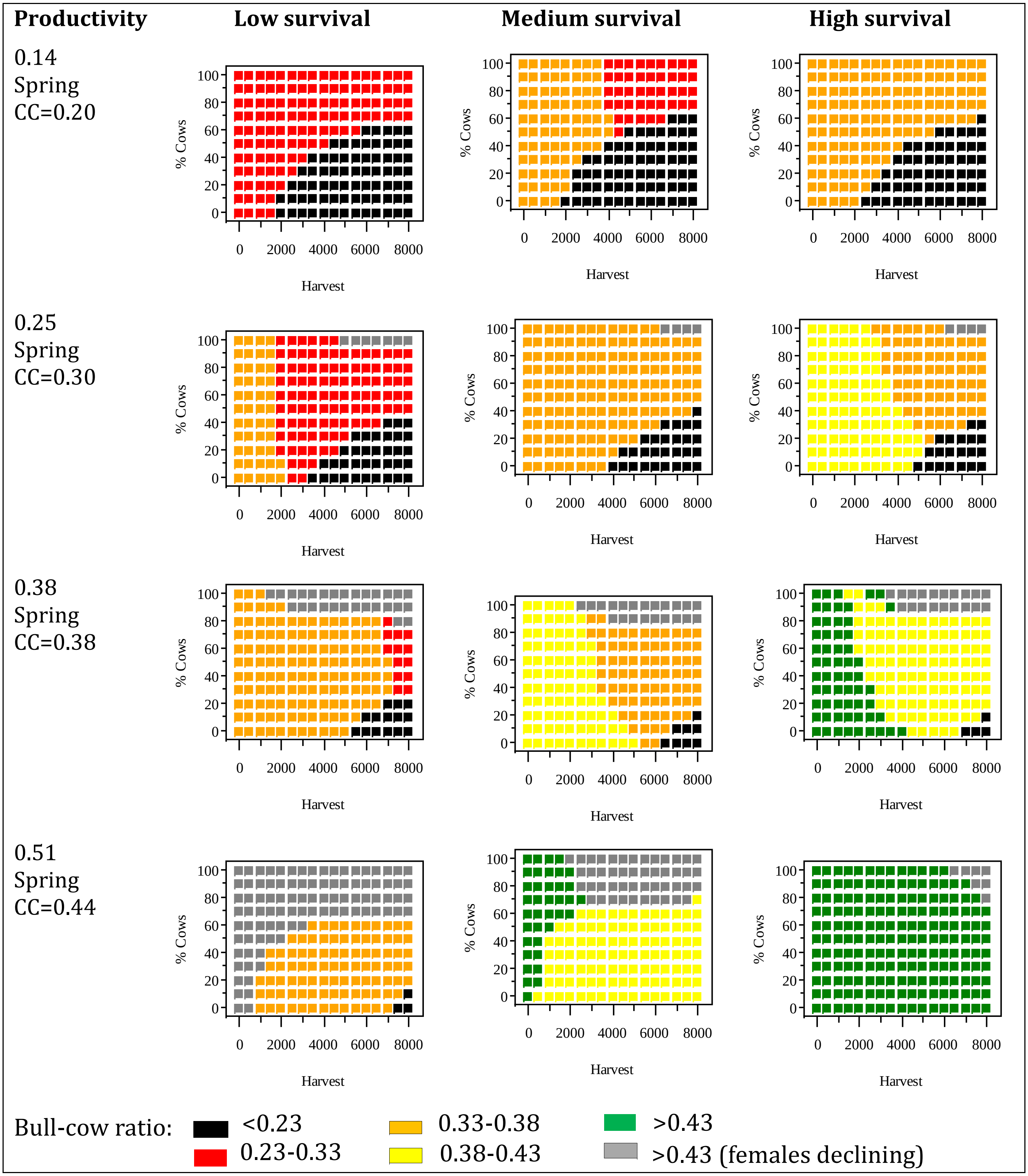



**Figure 9.** Bull-cow ratios after three years. Grey areas indicate higher bull-cow ratios that are partially due to declining cows and therefore should be interpreted cautiously. A value of 0.43 means a bull:cow ratio of 43 bulls: 100 cows.

The results of these simulations can be used to gauge relative levels of risk associated with harvest levels assuming an initial population size of 100,000 adult caribou. A relevant question is how risk varies with population size and proportion of the population harvested. We plotted the proportion of the adult herd harvested as a function of herd size after three years of simulations (Figure 10). From this it can be seen that overall risk is related to herd size with larger proportions of harvest acceptable when herd size is larger. However, it can be also seen that factors such as overall trend, and the proportion of females harvested will also influence risk. In fact, in the case of the simulations, herd size and trend are correlated at year three since only simulations with negative trends would cause a reduced total herd size. Harvest rates greater than 5% are only likely to be acceptable when a herd is large and has high survival and productivity. A good knowledge of a herd's demographics is essential in defining acceptable harvest recommendations.

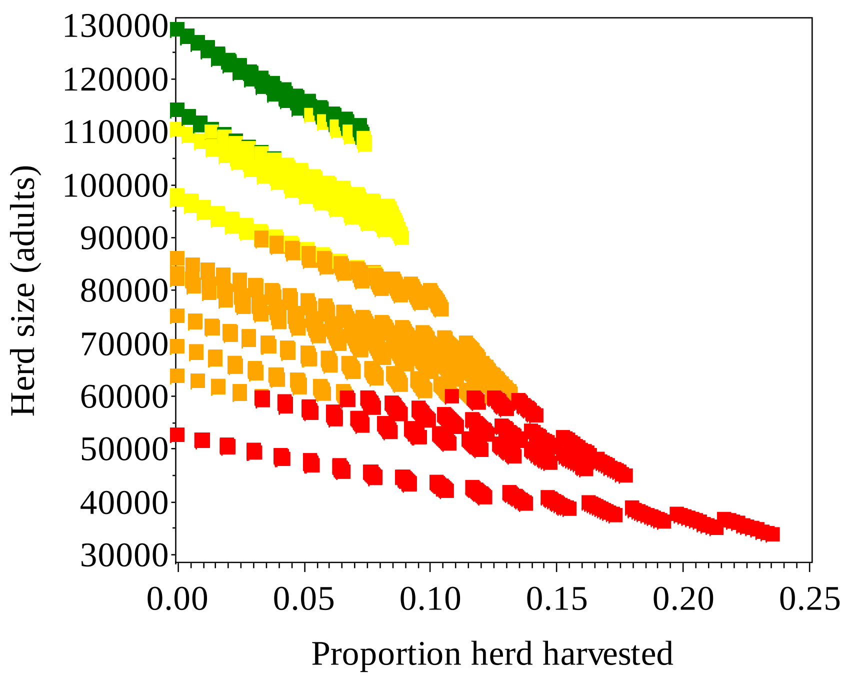



**Figure 10.** Proportion of herd harvested versus herd size at year three of simulations. Colors correspond to risk categories (Table 2).

## Case Study: Applying Harvest Modeling to the Bluenose-East and Bathurst Herds

Recent modeling for the Bathurst herd and Bluenose-East herd has suggested that adult female survival rates are lower than assumed in previous harvest modeling papers

(Boulanger and Adamczewski 2015, Boulanger 2016 In prep.). We therefore applied the results of recent studies for these herds to the harvest model to assess relative risk of herd at assumed harvest levels. We used estimates of demographic parameters from recent analyses conducted as part of the Bathurst 2012 survey (Boulanger et al. 2014a) and Bluenose East 2013 survey (Boulanger et al. 2014b). A summary of demographic estimates is given in Table 3.

**Table 3.** Indicators for Bathurst and Bluenose-East herds from analyses conducted from the 2012 Bathurst and 2013 Bluenose-East calving ground surveys (Boulanger et al. 2014a, Boulanger et al. 2014b).

| Indicator | Herd | |
|---|---|---|
| | **Bathurst (2009-12)** | **Bluenose-East (2010-13)** |
| **Adult female survival** | 0.78 | 0.75 (harvest of 2,600 assumed) |
| **Adult male survival** | 0.71 | 0.62 (harvest of 1,400 assumed) |
| **Productivity** | 0.38 | 0.26 |
| **Herd size** | 2012: 34,690 (CI=24,934-44,445) | 2013: 68,295 (CI=40,655-62,849) |
| **Population trend** | 0.99 (CI=0.86-1.08) | 0.87 (CI=0.85-0.91) |
| **Last Bull-cow ratio** | 2012: 0.57 (CI=0.51-0.64) | 2013: 0.426 (CI=0.39-0.46) |
| **Annual harvest** | <1,000 | 2,800-4,000 |
| **Proportion females harvested** | 0-40% | 65% |
| **Approximate proportion N harvested** | 1%* | 4-6% |

*Reported harvest for Bathurst has been <300/year but there is uncertainty as to true harvest due to overlap with Bluenose-East on winter range. A harvest of 300 is assumed here. Reported Bluenose-East harvest since 2010 has averaged 2,800/year but may be under-reported. A harvest of 2,800-4,000 is assumed here.

The population size and trend for the Bathurst herd puts it in the orange “moderate risk” category (box 12 in Table 2) mainly because the overall trend appears to be stable. The Bluenose-East herd also is placed into the orange (box 12) mainly because of the steep rate of decline even though the population size is still substantially larger than in the Bathurst herd. In both herds it is likely that substantial harvest will increase risk of serious decline.

The low levels of survival for the Bathurst and Bluenose-East put them into the lower survival scenario simulations (Table 1) with productivity at 0.38 for the Bathurst and productivity close to 0.26 for the Bluenose-East. We re-ran the harvest model with starting population sizes, bull survival rates and bull-cow ratios that were based on the 2012 (Bathurst) and 2013 (Bluenose-East) calving ground survey and evaluated the results based upon the low survival (0.77)-productivity=0.38 scenario for the Bathurst and low-survival-productivity=0.26 scenario for the Bluenose-East. The boxes predicting herd status for each herd at three years, power to detect change in three years, and bull-cow ratios are shown in Figure 11.

For both herds the majority of simulation outcomes result in a red risk category across most scenarios. If there is no harvest or harvest is low (<1,000) then the Bluenose-East remains in the orange category. This suggests that if lower survival levels continue the herd status will go into the red from the orange zone given likely harvest levels (Table 2). This is because of the low estimated survival values for both herds. For the Bathurst, levels of harvest of 2,000 or more result in the highest risk category (black) further demonstrating that this herd cannot tolerate significant harvest given its relatively low size. For Bluenose East, high harvest levels (>7,000) could also put the herd in the black zone given the relatively low level of productivity. In both cases power to detect decline in three years is high. For the Bluenose-East, bull-cow ratios will be reduced especially if bull harvest is high. If cow harvest is high (100%) and harvest is greater than 4,000 then bull-cow ratios could increase due to reduction in cow population size compared to bull population size (grey squares).

Interpretation of bull-cow ratios is more challenging given that bull-cow ratios were high (0.57) in 2012 for the Bathurst herd which placed it in the green zone in Figure 9. In this case, reduction of bull-cow ratios would not cause a significant risk to the herd since this level suggests there are a high proportion of bulls in the herd relative to cows. However, simulation results suggest that given the estimated ratios of bull and cow survival rates it is possible that the bull-cow ratio could increase (grey squares) under current levels of productivity (0.38) which would be partially due to female mortality. This is explained further in the Bathurst 2012 survey report (Boulanger et al. 2014b). Note that this effect becomes more pronounced if there is any female harvest mortality. Therefore, we suggest that any changes in bull-cow ratio for this herd be interpreted cautiously and in unison with other indicators.

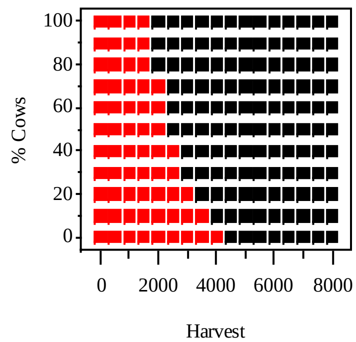
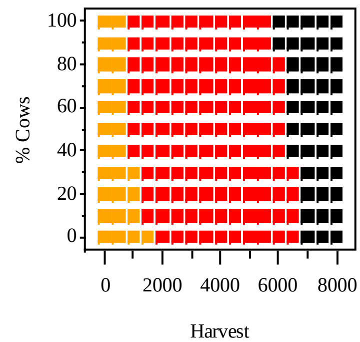
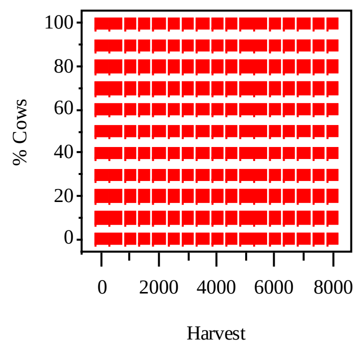
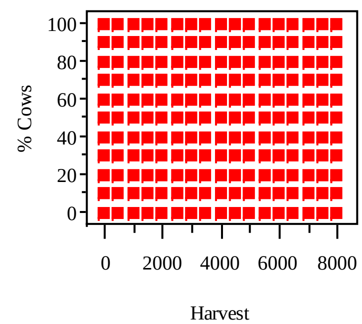
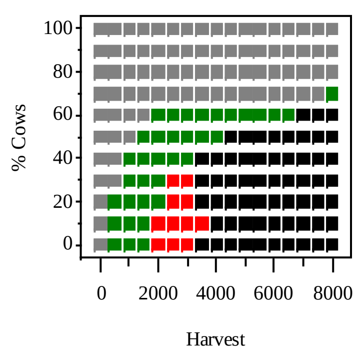
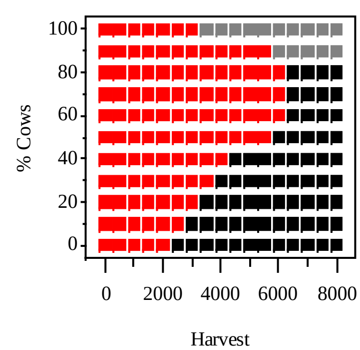
| Indicator | Bathurst<br>Low survival (0.77)<br>Productivity=0.38 | Bluenose-East<br>Low survival (0.77)<br>Productivity=0.26 |
|---|---|---|
| <u>Herd status in three years</u> (Figure 7).<br>Using initial N as starting point.<br><br>*Orange indicates moderate risk (Table 2)*<br><br>*Red indicates a high risk*<br><br>*Black indicates extreme risk.* |  |  |
| <u>Power to detect change at three years</u> (Figure 8)<br><br>*Red indicates that decline would be detectable.* |  |  |
| <u>Bull-cow ratios after three years</u> (Figure 9)<br><br>*Grey indicates cows declining.*<br><br>*Green indicates high (>0.43) b/c ratio*<br><br>*Red: bc=0.23-0.33*<br><br>*Black: bc<0.23* |  |  |

**Figure 11.** Herd indicators from harvest simulations as applied to the Bathurst and Bluenose-East herds with starting herd sizes and bull-cow ratios as listed in Table 3. Evaluations would occur at three years after population surveys *assuming constant survival and productivity rates.* Survival and productivity scenarios are detailed in Table 2.

## DISCUSSION

The results of these simulations illustrate how survival and productivity need to be considered when evaluating the risk of various harvest strategies. Demographic analyses of the Bathurst and Bluenose-East herds indicate lower natural survival rates suggesting that herds are declining even without harvest pressure (Boulanger et al. 2014a, b). Therefore, assessment of additional risk of decline due to harvest pressure is required given that a constant harvest on a declining population can accelerate population declines (Boulanger et al. 2011).

Adult survival rates determine the relative robustness of the herd to harvest and other perturbations whereas productivity ensures replacement of caribou. Monitoring of survival, productivity, and population size are therefore essential elements in sound population management. Even if collar sample sizes are low, it is still possible to estimate relative survival rates using the OLS model as has been done with the Bathurst and Bluenose-East herds. If survival estimates are not available, then consideration of relative trend and levels of productivity may give an indication of survival. The following sequence of steps could be used to initially assess likely survival values.

1. What is the trend of the herd?
2. What was the level of productivity in the previous years?
3. Given levels of productivity—is trend due to survival or productivity?
   a. If it is productivity then trend will most likely be less steep
   b. If it is survival then trend will be steeper
4. Divide harvest/female N—what proportion is being harvested?

These simulations are a simplification of herd dynamics in that they assume that demographic parameters are constant across individuals and time (White 2000). In reality, all demographic parameters vary and therefore the most appropriate way to view the future trajectory of a population as influenced by harvest is as a range of outcomes or probabilities of different target harvest levels (Boulanger and Adamczewski 2015, Boulanger et al. 2011, Boulanger 2013 In Prep.). The best use of the simulation results in this paper is to define general areas of higher risk. For example, simulations show that if productivity is low then only low to moderate harvest is acceptable to ensure that longer-term risk to the herd is minimized.

The simulations in this report assume that initial bull-cow ratios were similar to the Bathurst and Bluenose-East herds in recent years. The eventual bull-cow ratios at three and six year intervals were then influenced by bull and cow survival and relative levels of recruitment into the bull and cow segments of the herd, which would be related to productivity level. If initial bull-cow ratios were higher then it would be expected that a higher level of bull harvest might be possible. We note certain cases where increasing bull-cow ratios may be due to a decreasing cow population size and therefore naïve interpretation of ratios may be misleading. We suspect that a declining female segment of the population may be one reason for the increase of bull-cow ratios with the Bathurst herd (Boulanger et al. 2014a).

The initial herd size of 100,000 was based upon an average level of herd size to allow generalization of model results. However, when possible, a more exact analysis specific to a herd under particular conditions that considers variation in demography may be needed to assess risk of harvest. Harvest levels should always be considered in relation to overall herd size given that a harvest level of 5,000 will impact a herd of 25,000 very differently than a herd of 100,000 or a herd of 350,000 (Bathurst herd in 1990s). If bull-cow ratios and related demographic parameters are available, then simulations that are more tailored to individual herds should be pursued, as detailed in the Bathurst and Bluenose-East case studies. Deterministic simulations such as those documented in this paper could be useful to assess risk of harvest levels. Unlike stochastic simulations, deterministic simulations can be run very quickly and the methods presented in this manuscript should provide an intuitive way to interpret results. Stochastic simulations would provide the best assessment of risk with focused harvest strategies given that variation in demographic parameters would be considered. Consideration of stochastic variation would be most meaningful when herd size is smaller (<50,000 caribou) in which case temporal and demographic variation may have a larger impact on herd status compared to larger herd sizes.

The case studies of the Bluenose-East and Bathurst highlight one of the most important messages of this exercise which is that caribou demographics are likely to be temporally dynamic and therefore assessment of risk due to harvest or due to estimated survival rates should be undertaken frequently.

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## APPENDIX A: HARVEST RECOMMENDATIONS FOR BARREN-GROUND CARIBOU BASED ON HERD RISK STATUS: A RULE OF THUMB APPROACH

### Background

The Advisory Committee for the Cooperation on Wildlife Management (ACCWM)'s management plan for the Cape Bathurst, Bluenose-West and Bluenose-East caribou herds (ACCWM 2014) identifies an approach to hunter harvest management that assumes each herd will cycle between high and low numbers. Four colored zones are defined for each herd as (a) low (red), (b) decreasing (orange), (c) increasing (yellow), or high (green). Thresholds for transitions between these zones are defined based on the range of estimated herd sizes for the three herds, and harvest recommendations are proposed based on which zone the herd is in.

This approach is intuitive and pragmatic. However, there are two potential issues with this approach: (1) herds do not always cycle predictably, and (2) at best, reliable population estimates for the three herds only extend back to the late 1980s. Consequently, the basis for defining historic high and low levels and the associated thresholds between zones may sometimes be limited[1]. The Department of Environment and Natural Resources (ENR) has developed additional "rules of thumb" approach to help in defining harvest recommendations based on a herd's risk status, particularly its size and trend. This approach should be complementary to the type of recommendations on harvest in the ACCWM plan (2014) or other management plans. Harvest recommendations are meant to be revisited as new information on a given herd's risk status becomes available. The rule of thumb approach described here was based in large part of the general harvest modeling described in the main body of this report.

[1] The Fortymile herd in Alaska/Yukon numbered an estimated 568,000 in 1920, then declined rapidly and between 1940 and 1990 (50 years) remained between about 6,000 and 50,000 (Valkenburg et al. 1994). Bergerud et al. (2008) re-constructed approximate numbers of the George River (GR) herd in Labrador/Quebec from various sources and concluded that the herd reached high numbers around 1800, 1890, and 1990. Between 1890 and 1950, the GR herd was thought to have had two smaller peaks in numbers in about 1910 and 1925, with successively lower low numbers around 1900, 1920 and then 1940-1950. What constitutes a "high" and "low" herd size is less easily defined under these conditions.

## Harvest Management Context in the Northwest Territories

In the Northwest Territories (NWT), management of barren-ground caribou harvest is a shared responsibility between governments, co-management boards and communities. Recommendations and decisions about caribou harvest should in part reflect biological realities; that is, what the herd can tolerate. Management plans may also define varying priorities or goals for a herd; for example, recommended harvest for a herd might be different if the priority is maximizing hunting opportunities than if the priority is herd growth. The purpose of the approach described here is to help define a range of acceptable harvest options for a caribou herd based on its risk status. These options should be revisited in an adaptive manner when new information on the herd's risk status becomes available. Recommendations and decisions on harvest management will ultimately reflect a range of considerations, in particular the requirements of land claims and treaties, and management priorities defined through co-management.

## Harvest Modeling for Caribou

Population modeling was conducted to assess the likely effects of harvest varying in scale (% of herd) and sex ratio for herds varying in population size and trend. This work, along with earlier harvest/population modeling, was described in the main body of this report.

## Significance of Harvest to Barren-ground Caribou Herds

How harvest affects a caribou herd depends on a number of factors. Key ones are:

a) the herd's trend (increasing, stable, declining);
b) the rate (%) of the harvest in relation to herd size; and
c) the sex ratio of the harvest (proportion of cows in the harvest).

**Herd trend:** Increasing herds usually have high calf productivity and high adult survival rates; consequently, they are best able to withstand substantial hunter harvest. Modeling suggests that herds with high cow survival, sustained high calf productivity, and rapid rates of increase can tolerate annual harvest rates of up to 5-8% and continue to grow or be stable. These demographic conditions have not been observed in NWT's herds since the early 1980s. Conversely, herds with a declining natural trend usually have low calf productivity and low adult survival; consequently, mortality rates already exceed the rate at which yearling caribou are added to the herd. Under these conditions, harvest rates as low as 1-2% may increase the rate of decline.

For example, modeling of the Bluenose-East herd in 2012 suggested that if the herd's increasing trend and good calf recruitment as observed in 2010 continued, a harvest of 3,000 (2.5% of the 2010 herd size estimate of 122,000) was likely compatible with a stable herd. However, a decline in herd size was likely with a harvest of 5,000-6,000 (4-5% of estimated herd size in 2010).

**Harvest as % of herd size:** A harvest of 5,000 cows from a large and stable herd of 350,000 caribou is expected to have relatively little impact on the herd, since only a small fraction of the herd is harvested (just over 1%). However, a harvest of 5,000 cows from a herd of 30,000 would be 16.7% of the herd. A caribou herd could never produce enough young to sustain this level of harvest.

Harvest management plans or actions taken for a number of herds across Canada (e.g. Porcupine, George River, Cape Bathurst, Bluenose-West, Bluenose-East, and Bathurst) include possible harvest closure at very low numbers for conservation to allow the herd its greatest opportunity to recover.

**Harvest of cows and bulls:** Harvest of cows affects herds more strongly than harvest of bulls. Removing a breeding cow takes out the cow, the calf she is carrying, and all future calves she may produce. Although over-harvesting bulls is also not desirable, a healthy bull can breed many cows, while each cow typically only carries one fetus. The effect of harvesting a high proportion of cows is strongest in declining herds and the least in increasing herds with high calf productivity. Emphasis on bull harvest over cow harvest should be greatest in declining herds and/or herds at low numbers, and least in herds increasing and/or at high numbers.

**Sustainable and acceptable harvest:** Sustainable harvest from wildlife populations can be defined as harvest that does not cause a population to decline. By this definition, no harvest is sustainable from a caribou herd that has a declining natural trend. A limited harvest may be still be considered acceptable for declining caribou herds, with the understanding that substantial harvest (particularly that of cows) from a declining herd increases the risk of more rapid and extensive decline.

## Rule of thumb approach to harvest based on herd risk status

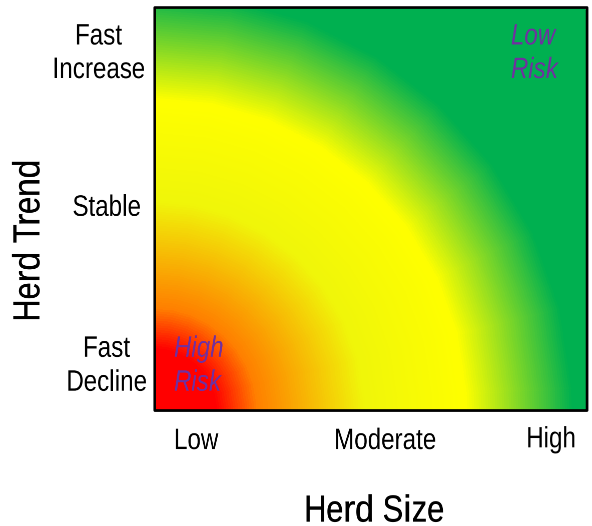


**Figure 1.** Assessment of risk status based on herd size and trend.

**Herd risk status based on size and trend:** Figure 1 shows how risk status of a caribou herd could be defined based on its size and trend (red - high risk; yellow - medium risk; green - low risk). A herd at relatively high numbers and increasing rapidly is at low risk of significant decline (green), while a herd already at low numbers and declining rapidly is at high risk of further significant decline (red). Recommendations on harvest would begin with a risk assessment of the herd.

**Other measures of herd risk status:** As described in the draft ACCWM caribou management plan, monitoring of caribou includes other indicators such as late-winter calf:cow ratios, fall bull:cow ratios, health and condition assessment, harvest, and information about predator numbers, herd accessibility, environmental indicators, and disturbance on the landscape. Information from people on the land is often the first indicator of change on the caribou range. These indicators could serve as additional ways of assessing the herd's risk status after herd size and trend are considered. Sustained low calf:cow ratios, caribou in consistently poor condition, high wolf numbers and increased levels of disturbance might be used to assess a herd as being at greater risk.

**Basing harvest level and sex ratio on herd risk status:** Figure 2 (below) shows how the rate (% of herd) and sex ratio of harvest could be adjusted to the herd's risk status. Acceptable harvest as a percentage of the herd should be limited in high-risk herds (1% or less of the herd) and increase to 2, 3 and 4% of the herd in lower-risk herds. In herds at very low risk and high numbers, harvest of 5% or greater would be acceptable. Emphasis on harvest of bulls-only or a high percentage of bulls in the harvest would be greatest in high-risk herds, while either-sex harvest would be acceptable in low-risk herds. A higher overall harvest rate could be considered in medium-high risk herds if it is predominantly a bull harvest; for example, this approach was used in harvest recommended for the Bluenose-West herd in 2007 (harvest rate of 4% and a bull biased harvest (80% bulls)).

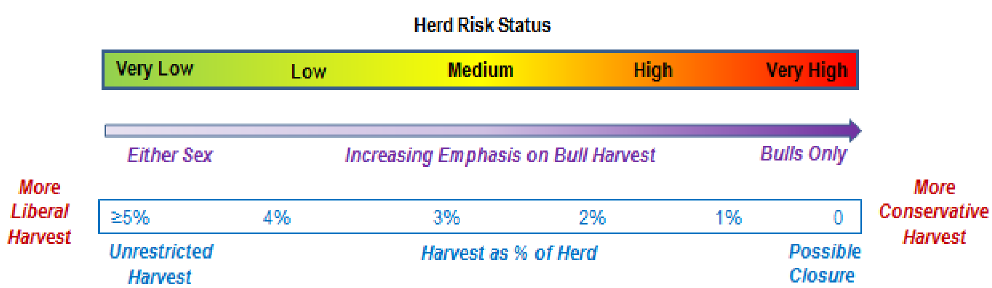


**Figure 2.** Suggested approach to recommending rate and sex ratio of harvest depending on a herd's risk status.

This approach could be used to define a range of options for harvest rate (% of herd) and harvest sex ratios appropriate to a herd of a particular size and trend, with consideration of other indicators. Additional indicators suggesting high risk might be low calf recruitment, poor condition assessed by hunters, accessibility of the herd's range to hunters, and substantial disturbance on key parts of the herd's range. In addition, consideration should be given to objectives for the herd: an emphasis on herd growth would be consistent with a lower harvest rate and a higher emphasis on bull harvest. An adaptive approach would include regular reviews of up-to-date information on herd status and reported harvest, and adjusting recommended harvest as needed. This approach would rely on on-going reliable reporting of harvest (numbers and sex ratio) by all hunters, whether the herds are large or small, and increasing, stable or declining.

### Examples of rule of thumb approach applied to harvest recommendations

In 2009, the Cape Bathurst herd was at very low numbers compared to earlier estimates (less than 2,000), with a stable trend and improving recruitment. All harvest had been closed for this herd in 2007. The herd's range is small and easily accessed by hunters. This herd's status could be assessed as High Risk given its very low numbers or Very High Risk based on its very low numbers and continued high accessibility. Continued harvest closure would help maximize the herd's opportunity to recover. If harvest was considered, it would likely be at a low rate (1% or less of the herd) with a high emphasis on a bull-only or predominantly bull harvest.

In 2010, the Bluenose-East herd was estimated at about 122,000 with an increasing trend and good recruitment (Adamczewski et al. 2014). Based on the herd's trend and relatively large size, it would likely be assessed as being at Low-Medium risk. If the management goal was to give priority to a stable trend and a strong chance of continued herd growth, a conservative approach to harvest would be 2-3% of herd size with strong promotion of bull harvest. A more liberal approach to harvest would be 4% of the herd with a sex ratio including a substantial percentage of cows. This approach would give priority to maximizing harvest opportunities but would carry a higher risk of population decline.

Since 2010, the Bluenose-East herd was declined substantially to about 68,000 in 2013 and at a more rapid rate, to about 38,600 caribou in 2015 (see Boulanger et al. 2016 In Prep.).

Its large loss of numbers and rapid rate of decline would place it in a high risk category where any further harvest would need to be carefully considered and should include a high bull or all bull component.

Table 1 (below) includes a summary of the rule of thumb approach that includes possible approaches to resident and commercial harvest of caribou. The underlying elements of the summary are borrowed from management plans or proposed harvest management for the Porcupine, George River, Bathurst, Beverly, Qamanirijuaq, Bluenose-West, Bluenose-East and Cape Bathurst herds, and harvest modeling carried out by ENR for the Bathurst and Bluenose-East herds.

**Table 1.** Rule of thumb approach to recommending rate and sex ratio of harvest for barren-ground caribou based on risk status, with possible approaches to Aboriginal, resident and commercial harvest.

Herd Risk Status: Very Low, Low, Medium, High, Very High

| Suggested Acceptable Harvest (% of herd) | Recommended Aboriginal Harvest | Recommended Resident Harvest (assuming unrestricted Aboriginal harvest) | Recommended Commercial/Outfitter Harvest (assuming unrestricted Aboriginal harvest) |
|---|---|---|---|
| **5 % or higher** | Unrestricted, either sex | ≥2 bull tags/hunter | Limited commercial tags |
| **3-5 %** | Unrestricted, promote bull harvest | 2 bull tags/hunter | Limited commercial tags |
| **2-3 %** | Unrestricted, promote bull harvest | 1 bull tag/hunter; possible limit on tags | Either no commercial tags or small numbers of tags |
| **<2 %** | Promote conservation voluntary bulls only | 1 bull tag/hunter; possible limit on tags | No commercial tags |
| **<1 %** | Consider mandatory bulls only | No resident tags | No commercial tags |
| **0.01 %** | Consider closure; harvest for social/ceremonial reasons | No resident tags | No commercial tags |

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