A general approach to harvest modeling for caribou herds in the NWT – draft recommendations report

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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 to 8000, and sex ratio of the harvest varied from 0% to 100% cows. Time-steps of 3 and 6 years were used to match the frequency of recent GNWT 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 3 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.

1. Introduction

In the wake of declines in all barren-ground caribou herds monitored by 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). 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 2010 and Boulanger et al. 2011).

Long-term management planning for these herds, the Bluenose-East herd, and for the Beverly and Qamanirjuaq herds is either underway or planned. 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.

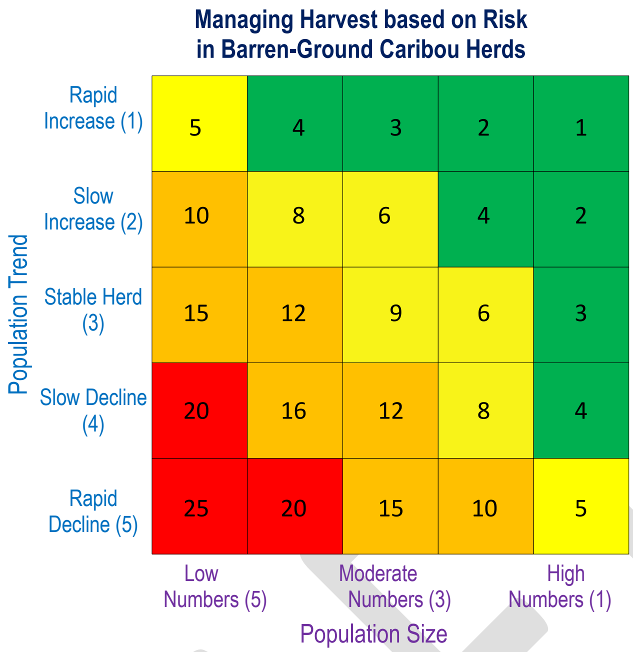


Figure 1: Relative levels of risk as a function of population trend and size.

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.

2. Methods

The underlying model used for simulations was similar to the demographic model used for the Bathurst herd (Boulanger and Adamczewski 2010, Boulanger et al. 2011, Boulanger 2013). 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 3 and 6 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 3 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 3 years after a harvest regime is imposed.

1.1. 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.

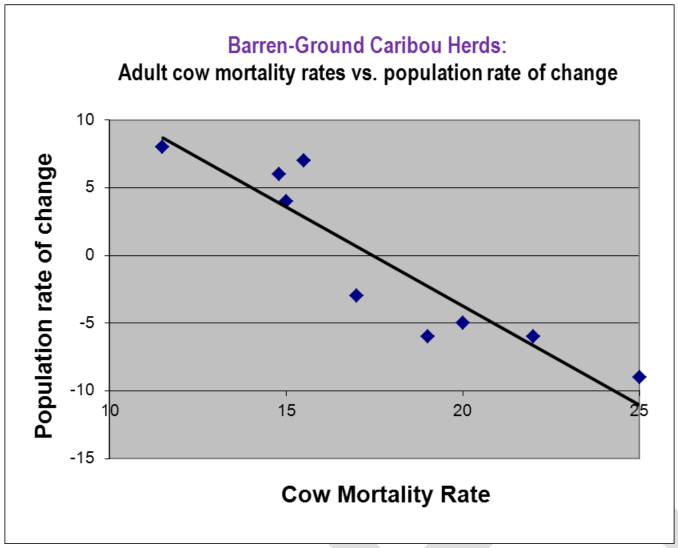


Figure 2: Empirical relationship between caribou adult cow survival rates and population rate of change (courtesy of Don Russell, CARMA, pers. comm.).

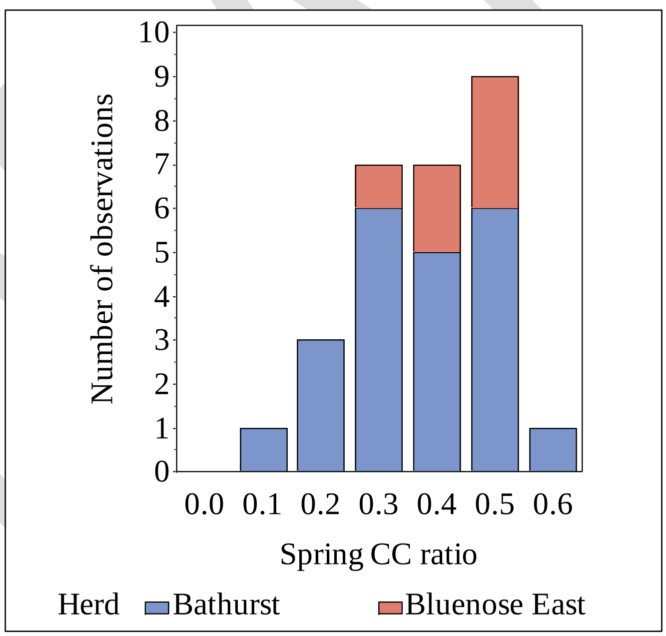


Figure 3: Ranges of spring (March-April) calf-cow ratios for the Bathurst herd (1985-2012) and Bluenose-East (2007-12) caribou herds.

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 10 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 to 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.

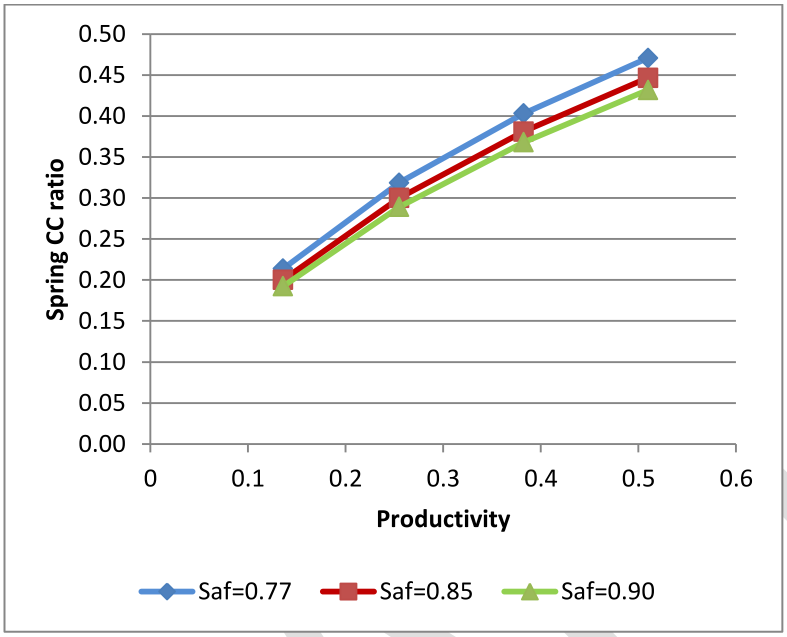


Figure 4: Productivity values with corresponding calf-cow ratios. Various values of adult survival (Saf) are given. Other parameters are listed in Table 1.

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). Asympotic λ values for females and calf cow ratios are also given.

Survival Scenario	Productivity	Survival Cow	Survival Bull	Survival Calf	Survival Yearling	Fecundity	Initial Breed F N*	Female Trend λ	CC* ratios Spring	CC* ratios 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.

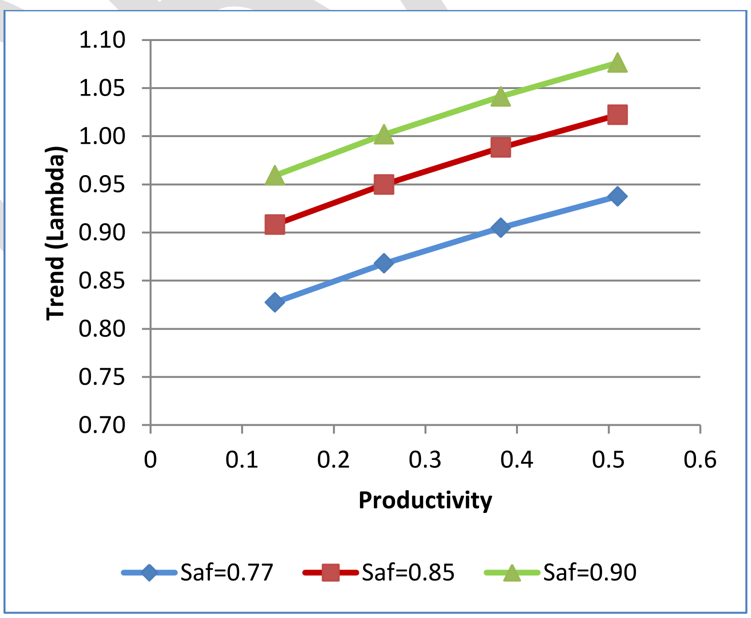


Figure 5: Trend in female population size as a function of productivity and adult female survival.

1.2. 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 3 and 6 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).

1.3. 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 2 different combinations of herd size and trend.

2. 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 (Figure 6) at 3 years and at 6 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 0 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 3 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 0 harvest. In most other scenarios risk was moderate to low. However, this result was potentially misleading since a decreasing population would only have 3 years to decrease therefore the longer-term risks of various harvest strategies may not be as evident. If the same simulations are evaluated at 6 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 3 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 NWT 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.

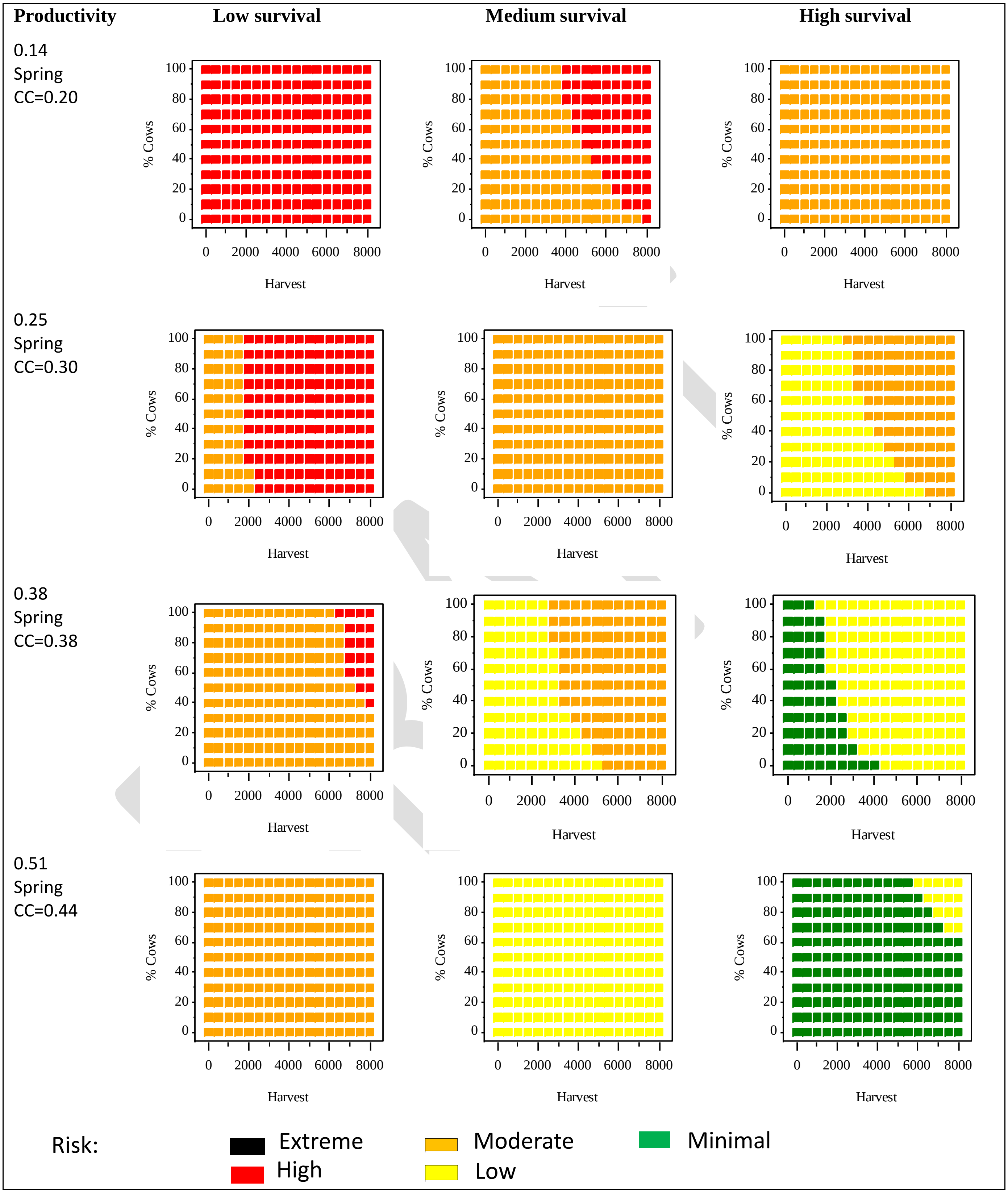


Figure 6: Relative risk of various harvest strategies when evaluated at 3 years. Risk categories are defined in Table 2.

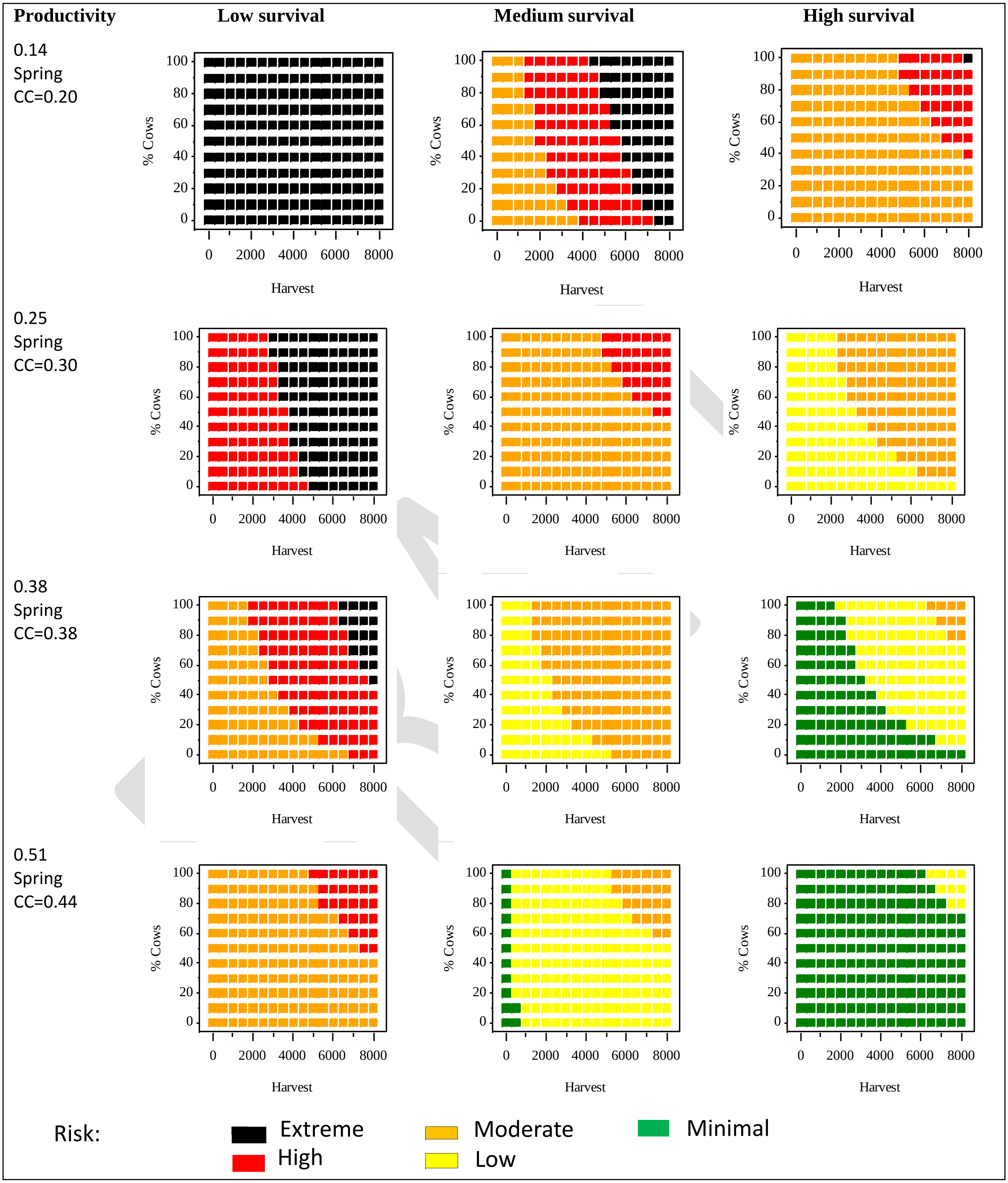


Figure 7: Relative risk of various harvest strategies when evaluated at 6 years. Risk categories are defined in Table 2.

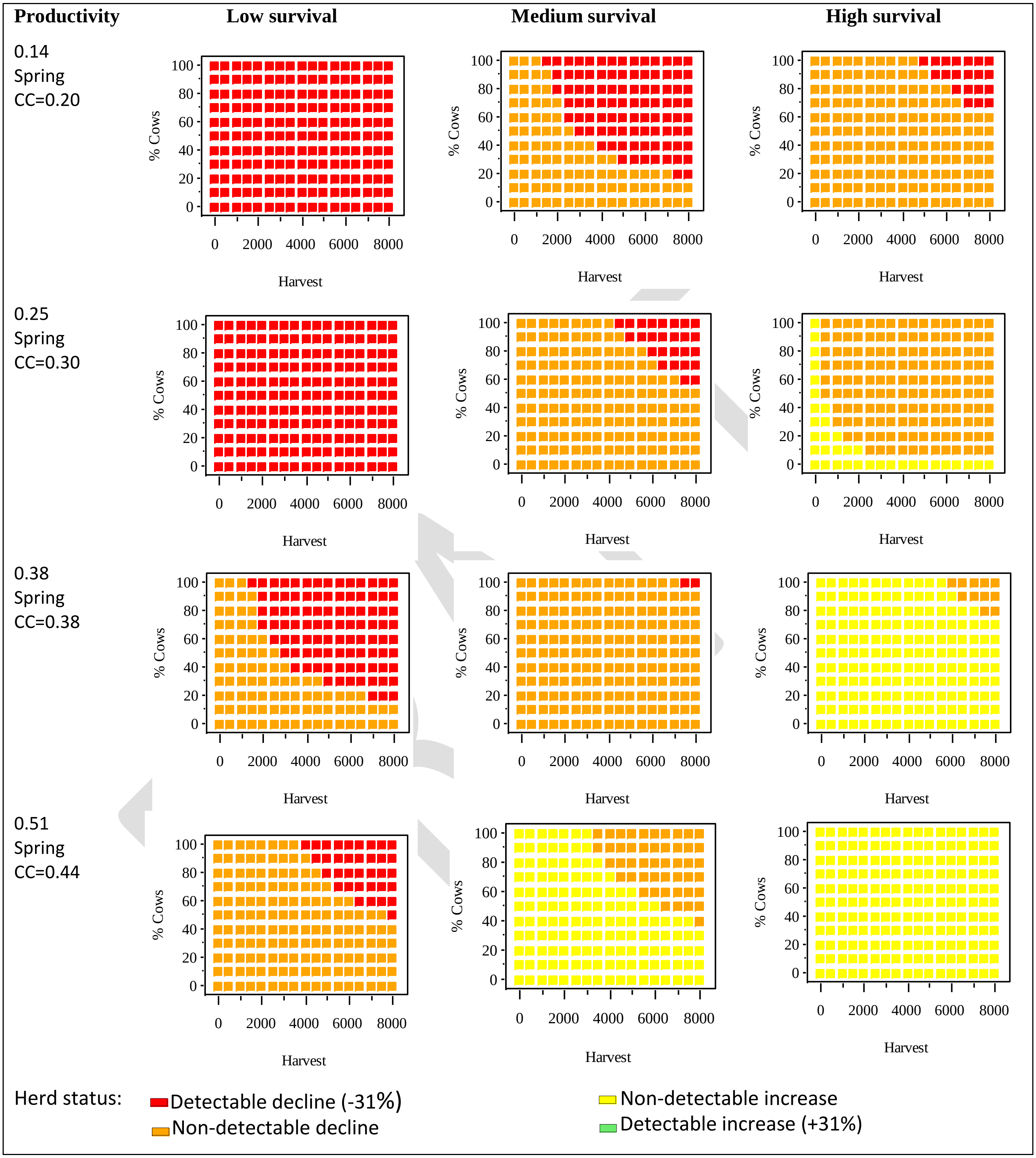


Figure 8: Power to detect change at 3 years based on various harvest levels. Red denotes that a negative trend was detected (at least 31% decline) whereas orange would be a non-detectable decline, yellow a non-detectable increase and green a detectable increase of at least 31%.

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.

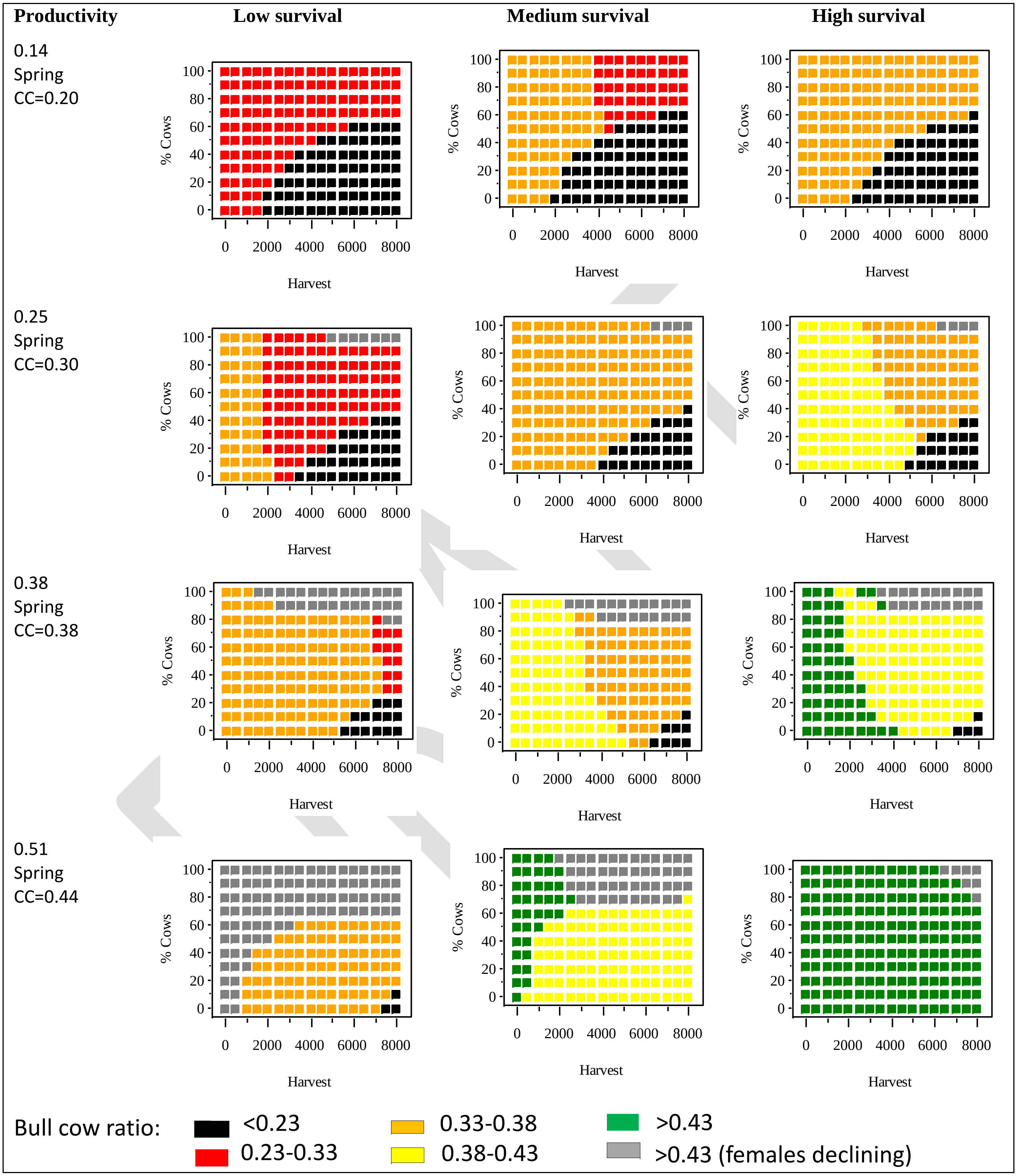


Figure 9: Bull-cow ratios after 3 years. Grey areas indicate higher bull cow ratios that are partially due to declining cows and therefore should be interpreted cautiously. A value of 0.43 means a bull:cow ratio of 43 bulls: 100 cows.

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 3 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 3 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.

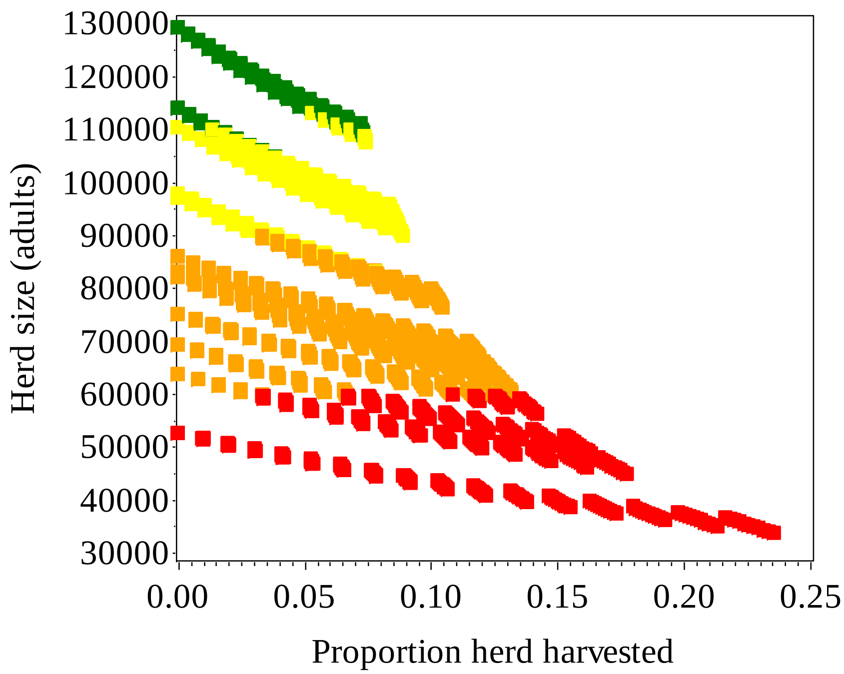


Figure 10: Proportion of herd harvested versus herd size at year 3 of simulations. Colors correspond to risk categories (Table 2).

2.1. 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 model papers (Boulanger and Adamczewski 2010, Boulanger 2013). 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. 2013) and Bluenose East 2013 survey (Boulanger et al. 2014). 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. 2013a, Boulanger et al. 2014).

Indicator	Herd	
	Bathurst (2009-12)	Bluenose-East (2010-13)
Adult female survival	0.78	0.75 (harvest of 2600 assumed)
Adult male survival	0.71	0.62 (harvest of 1400 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 to 1.08)	0.87 (CI=0.85-0.91)
Last Bull-cow ratio	2012: 0.57 (0.51-0.64)	2013: (0.426 CI=0.39-0.46)
Annual harvest	<1000	2800-4000
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 2800/year but may be under-reported. A harvest of 2800-4000 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 3 years, power to detect change in 3 years, and bull cow ratios are shown in Figure 11.

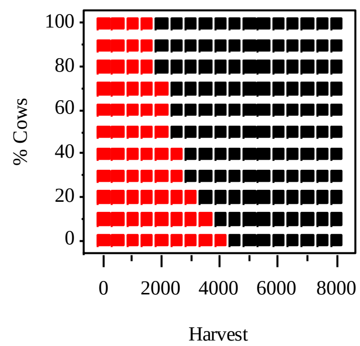
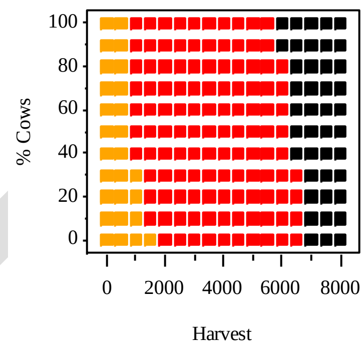
For both herds the majority of simulation outcomes result in a red risk category across most scenarios. If there is no harvest or harvest is low (<1000) then the Bluenose-East remains in the orange category. This suggests that if lower survival levels continue the herd status will go into the red from 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 2000 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 (>7000) 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 4000 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. 2013a). 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.

<table>
<tr><td>Indicator</td><td>Bathurst
Low survival (0.77)
Productivity=0.38</td><td>Bluenose-East
Low survival (0.77)
Productivity=0.26</td></tr>
<tr><td><u>Herd status in 3 years</u> (Figure 7). Using initial N as starting point.

Orange indicates moderate risk (Table 2)

Red indicates a high risk

Black indicates extreme risk.</td><td>
</td><td>
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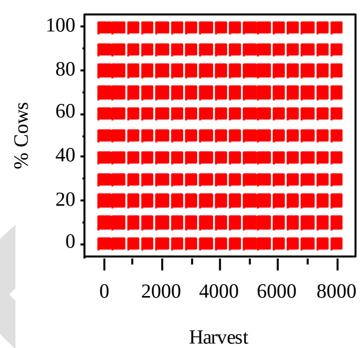
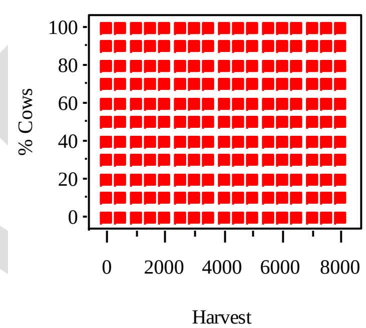
<tr><td><u>Power to detect change at 3 years</u> (Figure 8)

Red indicates that decline would be detectable.</td><td>
</td><td>
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<tr><td><u>Bull cow ratios after 3 years</u> (Figure 9)

Grey indicates cows declining.

Green indicates high (>0.43) b/c ratio

Red: bc=0.23-0.33

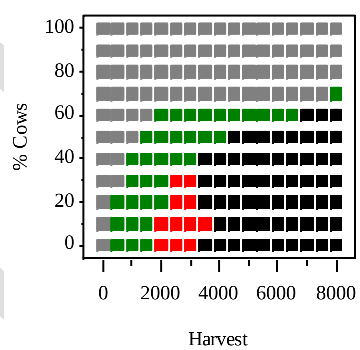
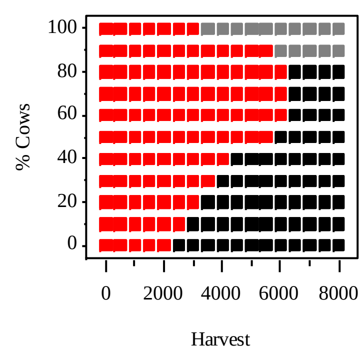
Black: bc<0.23</td><td>
</td><td>
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Figure 11: Herd indicators from harvest simulations as applied to the Bathurst and Bluenose-East herds with starting herd sizes and bull cow ratios as listed in Table 3. Evaluations would occur at 3 years after population surveys *assuming constant survival and productivity rates.* Survival and productivity scenarios are detailed in Table 2.

3. Discussion

The results of these simulations illustrate how survival and productivity need to be considered when evaluating the risk of various harvest strategies. 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 herd. 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 2010, Boulanger et al. 2011, Boulanger 2013). 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 3 and 6 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 than 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. 2013b).

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.

4. Literature cited

Adamczewski, J., Boulanger, J., Croft, B., Cluff, D., Elkin, B., Nishi, J., Kelly, A., D'Hont, A., and Nicolson, C. 2009. Decline in the Bathurst caribou herd 2006–2009: a technical evaluation of field data and modeling. Environment and Natural Resources, Government of Northwest Territories, Yellowknife, NWT, Canada. (http://www.wrrb.ca/sites/default/files/public_registry/Technical%20Report%20of%20Bathurst%20herd%2017%20Dec%2009.pdf).

Bergerud, A.T., Luttich, S.N., and Camps, L. 2008. The return of caribou to Ungava. McGill-Queen's University Press, Canada.

Boulanger, J. 2013. Exploration of harvest strategies for the Bluenose East caribou herd, draft contract report October 15, 2012. Environment and Natural Resources, GNWT, Yellowknife, NT. Manuscript Report (in prep.).

Boulanger, J., and J. Adamczewski. 2010. Simulations of Harvest and Recovery for the Bathurst Caribou Herd, with Annual Variation. Environment and Natural Resources, Govt. of Northwest Territories, Yellowknife, NT. Manuscript Report 237 (in press).

Boulanger, J., B. Croft, and J. Adamczewski. 2013. An estimate of breeding females and analyses of demographic indicators from the Bathurst herd 2012 calving ground photographic survey. Environment and Natural Resources, Government of Northwest Territories.

Boulanger, J., B. Croft, and J. Adamczewski. 2014. An estimate of breeding females and analyses of demographics for the Bluenose-East herd of barren ground caribou: 2013 calving ground photographic survey. Department of Environment and Natural Resources, Government of Northwest Territories, Yellowknife, NT. File report (in prep.).

Boulanger, J., A. Gunn, J. Adamczewski, and B. Croft. 2011. A data-driven demographic model to explore the decline of the Bathurst caribou herd. Journal of Wildlife Management 75:883-896.

White, G. C. 2000. Population viability analysis: Data requirements and essential analyses. Pages 289-331 *in* L. Boitani, andT. K. Fuller, editors. Research techniques in animal ecology: Controversies and consequences. Columbia University Press, New York, New York, USA.

Zalatan, R., Gunn, A., and Hare, G.H.R. 2006. Long-term abundance patterns of barren-ground caribou using trampling scars on roots of Picea mariana in the Northwest Territories, Canada. Arctic, Antarctic and Alpine Research 38:624-630.