Government of Northwest Territories Gouvernement des Territoires du Nord-Ouest

Exploration of Harvest Strategies for Bluenose-East Caribou Herd using Post-calving Based Estimates of Herd Size in 2010

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ABSTRACT

In July 2010 a post-calving survey of the Bluenose-East caribou herd resulted in a population estimate of about 123,000 caribou at least one year old, with an increasing trend and good calf recruitment. The analyses described in this report were carried out to assess the likely impacts on the herd of annual harvest levels of 3,000, 5,000, and 6,000 caribou with 0, 34, 50, 67 and 100% bulls in the harvest. Cow survival was constant at 88% and calf productivity levels were 18, 38 and 57%. Stochastic variation in calf productivity was simulated to provide a range of outcomes for each set of conditions and time-steps of three, six and nine years were used to match the recent intervals between population surveys for NWT barren-ground caribou herds. The main conclusion from simulations was that given current levels of productivity and a continuing high cow survival rate, the Bluenose-East herd in 2010 could sustain moderate (3,000) harvest especially if a large proportion of the harvest is comprised of bulls. If harvest is increased to 5,000 then harvest should have a dominant bull component (>50%) to avoid risk of substantial longer-term decline. Fundamental assumptions of the simulations are that productivity will remain at the three year average level and cow survival at 88%. If productivity is lower (as in 2012) or if adult survival declines, then herd size will be more influenced by harvest, leading to more detectable declines. Adaptive adjustment of harvest levels with more recent information about productivity and cow survival rates is essential.

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INTRODUCTION

In this report I explored scenarios for harvest with the Bluenose-East herd under varying levels of harvest and management regimes based on the herd's size and demographics as estimated in 2010. This work used the stochastic population model as developed by Boulanger and Gunn (2007) and Boulanger et al. (2011) to simulate variation in demographic parameters in caribou herds. This work updates a previous report by using estimates of herd size from a post calving photo survey of the herd in 2010 (Adamczewski et al 2014), rather than extrapolated herd size estimates from calving ground surveys as a basis for simulations.

I note that the simulations in this report were based upon indirect estimates of adult female survival rates based on 2010 herd size and demographics. A survey in June 2013 documented a substantial decline in herd size between 2010 and 2013 (Boulanger et al 2014) and analyses estimated natural adult female survival at 0.74 in 2013, assuming an annual harvest of 4,000 caribou and 65% cows (Boulanger et al 2014). A further survey in June 2015 (Boulanger et al. 2016) indicated that the decline 2010-2013 had accelerated between 2013 and 2015, underscoring the need for a very careful approach to harvest of this herd. Therefore, the simulations in this paper do not directly apply to Bluenose-East demography and ability to sustain harvest after 2010. A more general approach to deterministic modeling of harvest of various sizes and sex ratios in barren-ground caribou herds with a range of cow survival rates and calf productivity levels was reported by Boulanger and Adamczewski (2016) with a case study of the Bluenose-East herd in 2013. We suggest readers refer to this report for updated information on Bluenose-East trend and harvest recommendations appropriate to the herd's demographics. The simulations in this report provide an example of a stochastic approach to exploring harvest based on risk for the herd in 2010 that builds on stochastic modeling for the Bathurst herd in 2010 (Boulanger and Adamczewski 2015).

A stochastic model is basically a simulation model that is run hundreds of times with variation in demographic parameters simulated. The advantage of using a stochastic approach is that the outcomes include a range of possible "futures" for the herd. In the natural world, calf survival, pregnancy rate, and other variables change from year to year. The outcomes of stochastic modeling identify the most likely trends under a particular set of conditions, but they also make clear that there is uncertainty around those likely trends.

The main objective of this exercise was to use the stochastic model as an aid in setting management targets (i.e., herd sizes), and objectives while appropriately considering the uncertainty caused by natural variation in population parameters. Given uncertainty in Bluenose-East herd demography, any management of the Bluenose-East caribou herd should be adaptive with management goals that respond to future information on productivity, harvest, and other demographic indicators. Therefore, the model also generates predictions of all applicable demographic indicators as well as ranges of future herd sizes. The specific objectives of this exercise were as follows:

- Assess overall risk associated with various management actions and population level targets as a function of natural variation in herd productivity and hypothetical harvest levels.

- Assess the probability of future herd sizes as based upon management objectives as well as the power to detect changes in population size. The monitoring interval between surveys is explicitly considered since this affects the power to detect population change.

- Predict field-based estimates of fall bull-cow ratios, calf-cow ratios, and breeding female numbers to be used in an adaptive management context to further refine management goals and simulations as more data become available.

METHODS

I considered a set of scenarios of varying herd productivity concurrently with variation in adult female survival as influenced by harvest levels, in consultation with ENR biologists. Productivity is difficult to control or manage (compared to mortality/harvest) and therefore it was important to consider all simulations across a range of likely productivity levels.

Scenarios of Adult Productivity

Productivity can be conceptualized as the proportion of breeding age females that produce a calf that survives to become a yearling. Therefore the two parameters that directly affect productivity are fecundity and calf survival. In addition, adult female survival can affect productivity. The most direct estimate of productivity comes from calf-cow ratios in the spring. Calf-cow ratios for the Bluenose-East herd suggest a range from 0.48 in 2007 to 0.27 in 2012 (Figure 1).

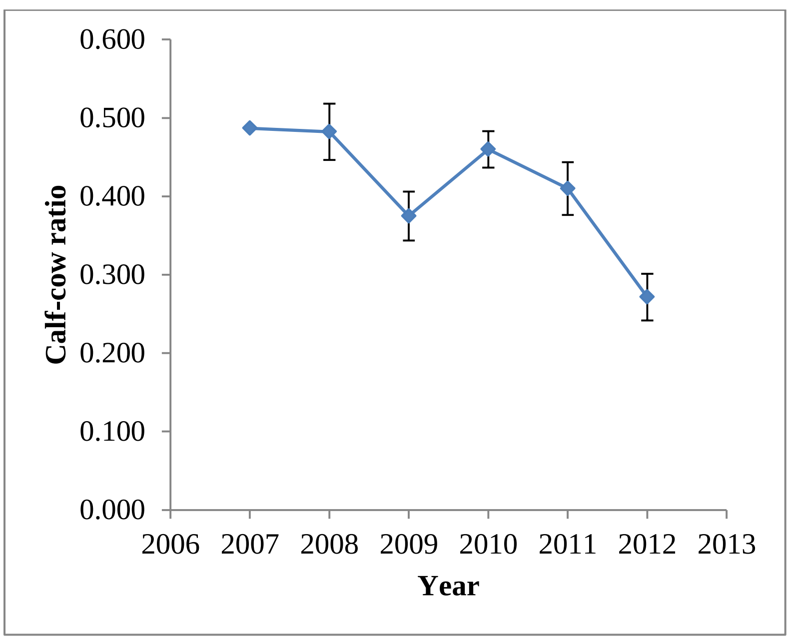

Figure 1: Calf-cow ratios for the Bluenose-East herd from spring composition surveys 2007-2012.

An initial set of simulations were run to allow a cross reference of productivity scenarios and observed spring calf cow ratios. From this, a range of productivity scenarios were established that spanned the observed range of calf-cow ratios 2007-2012 for the Bluenose-East herd (Table 1). The three year average productivity scenario (0.38) which encompassed the most recent values since the last calving survey in 2010 was a primary focus of simulations.

Table 1: Productivity scenarios considered in simulations for the Bluenose-East herd in 2010. Calf survival (S_c) and proportion females pregnant (F_a) were varied to produce productivity values. Simulations were run to estimate corresponding spring calf-cow ratio values.

Scenario	S_c	F_a	Productivity (Sc*Fa)	Approximate Spring Calf-Cow Ratio
Low (2012)	0.22	0.83	0.18	0.25
Average; last 3 years (2010-12)	0.40	0.95	0.38	0.36
High	0.6	0.95	0.57	0.45

I note that each productivity scenario and associated level of productivity should be interpreted as a *distribution* of simulated productivity values as shown in Figure 2, rather than *a single mean value* given that the variance in productivity is also considered in simulations. For example, Figure 2 shows the range of calf-cow ratios that were produced for the three year average scenario. Mean calf-cow ratios were 0.36 for simulations but values ranged mainly from 0.2-0.5. Therefore, yearly variation in productivity was considered during simulations.

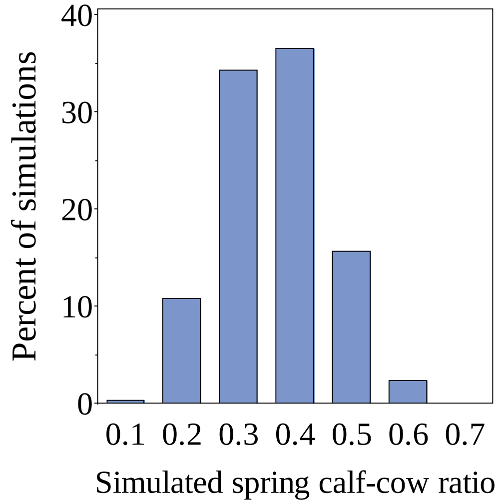

Figure 2: Distributions of calf cow ratios from simulations with the three year average productivity (2010-2012) for the Bluenose-East herd in 2010**.**

Monitoring of productivity is an essential step of adaptive management. If productivity levels that are substantially different than levels simulated are observed in the next few years than further productivity scenarios could be run to further focus simulation model outcomes. For example, the lower productivity scenario (Table 1) corresponded to the most recent (2012) estimated calf-cow ratios, and this scenario would be most likely if low calf-cow ratios are observed in future years.

Values for Demographic Parameters

Adult survival values were not available for the Bluenose-East caribou herd in 2012 and therefore similar survival values were assumed to be similar to the Bathurst herd. I note that hunting mortality is subtracted from these values as further discussed in Boulanger and Adamczewski (2015). Boulanger et al. (2011) also estimated biological or process variation in demographic parameters (Table 2). Process variance is basically the amount that parameters vary by individual and on a yearly basis. For example, factors such as weather and range condition will influence fecundity and calf survival. By analyzing the time series of productivity estimates from the Bathurst herd it was possible to estimate both yearly and individual variation. These estimates were also used for the harvest simulation. Directional change in parameters was not simulated beyond the effect of constant harvest on adult male and female survival rates.

Table 2: Process variation for demographic parameters as detailed in Boulanger et al. (2011) and used in present simulations. This is the natural variation that occurs in these parameters as estimated from field data.

Parameter	Estimate	CV (Individual)	CV (Time)
Adult female survival (S_f)	0.88	0.10%	3.15%
Adult male survival (S_m)	0.72	0.10%	3.15%
Fecundity (F_a)	0.83-0.95[A]	8.50%	1.39%
Calf survival (S_c)	0.22-0.60 [A]	12.70%	36.79%
Yearling survival (S_y)	0.86	12.70%	3.15%

[A]The value depended on productivity level simulation as indicated in Table 1.

Initial Population Sizes for Simulations

This current round of simulations used an estimate of total herd size of 122,697 (SE=16,202.2, CI=90,940-154,452, CV=13.21%) from the 2010 post calving survey as a baseline for population size (Adamczewski et al. 2014). This estimate was higher than calving ground extrapolated estimates from the 2010 survey (102,704±20,355) which was due to the inclusion of yearlings of the previous year in the estimate. This estimate was also larger than the total count of caribou on the calving ground of 114,472±6,908 (Adamczewski et al. 2014). The difference in this case was due to the inclusion of bulls and yearlings that may not have been on the actual calving ground during the survey but were present during post calving surveys.

Given that total herd size was the starting point of simulation, allocation of the herd size to the various age and sex classes was required. Allocation of males and females was based upon the fall bull-cow ratio and related estimates of proportion cows in the herd. Allocation of yearlings was based on the assumption of a stable age distribution that was related to relative productivity of the herd for the year of the survey and year preceding the survey. POP-TOOLS (Hood 2009) in Excel was used to estimate stable age distributions for simulations. Assuming a productivity level that corresponded to the average 2010 and 2011 spring calf cow ratio (of 0.43) an estimate of 72,051 cows, 36,290 bulls and 14,355 yearlings was derived under the assumption of a stable age distribution.

It was possible to cross-check these starting values using estimates from the 2010 calving ground survey (Adamczewski et al. 2014). From the calving ground survey, it was estimated that there were 71,885 (CI=49,319-94,450) cows, 30,819 (CI=18,802-42,836) bulls and 15,009 yearlings (CI=11,666-18,353). Comparison of these estimates with the model-based starting values suggested that yearling and cow estimates were similar, but estimates of adult males were higher (Figure 3). This difference was presumably due to the fact that bulls were potentially under-counted on the calving ground (Adamczewski et al. 2014). Therefore, the increased mean number of males for simulations was justifiable given that the starting values were based upon post-calving estimates which would have detected males that were not present on the calving ground.

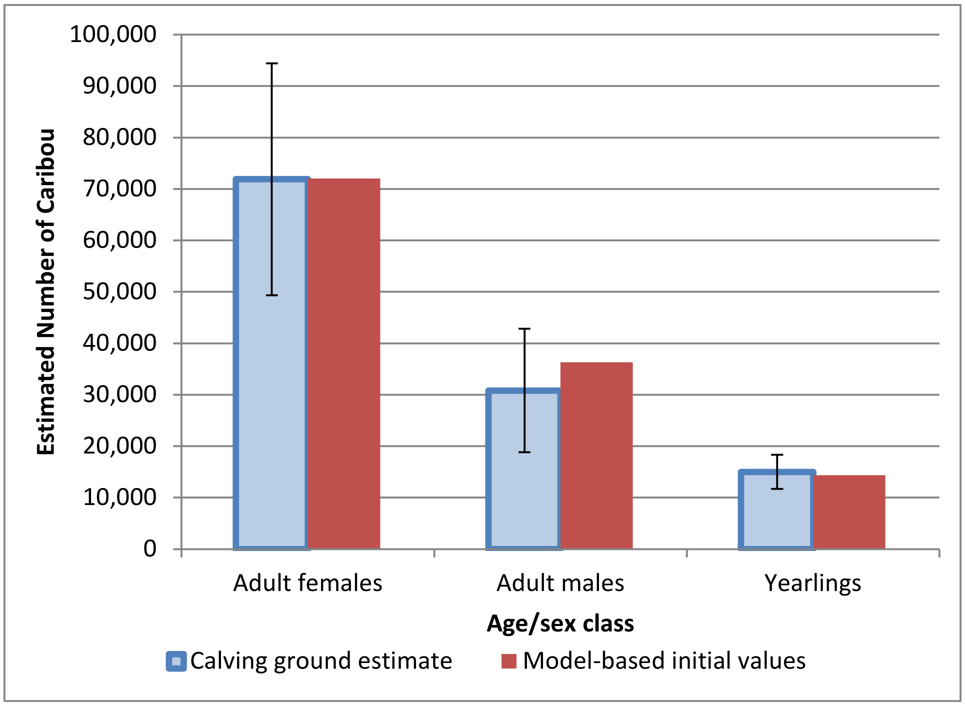

Figure 3: Estimated numbers of adult cows, females, and yearlings in the Bluenose-East herd in 2010 from calving ground surveys, fall composition surveys, and assumed pregnancy rates (Table 3).

Harvest Levels Simulated

The effect of harvest was explicitly considered in simulations. For example, it was assumed that harvest of bulls occurred in the fall and harvest of cows in mid-winter, and this factor was considered when producing simulated fall bull-cow ratios. Actual harvest levels were based upon reported levels (Adamczewski et al. 2016) for fall and winter 2009-2011 (Table 3). On average, 413.3 and 2,303 caribou were harvested in the fall and winter for an overall average annual harvest of 3,130. In general, bulls were mainly harvested in the fall (94%) whereas cows were more likely to be harvested in the winter (63%). The overall annual ratio of bulls to cows harvested was 49% bulls and 51% cows. These figures are likely underestimates and therefore harvest levels of 3,000 and 5,000 caribou were considered in simulations.

Table 3: Reported harvest levels for the Bluenose-East herd 2009-2011 (Adamczewski et al. 2016).

Year	Fall				Winter				Total (Fall + Winter)		
	Bull	Cow	Unk[A]	Total	Bull	Cow	Unk	Total	All	Bulls	Cows
2009	1,056	0		1,056	844	1,567		2,410	3,466	1,900	1,567
2010				0	480	638	1,800	2,918	2,918	480	638
2011	59	71	54	184	420	713	449	1,582	1,766	479	784
Sum	1,115	71	54	1,240	1,744	2,918	2,249	6910	8,150	2859	2,989
Average	371.7	23.7	18.0	413.3	581.2	972.5	749.7	2,303.3	2,716.7	952.8	996.2
Proportion	0.94	0.06			0.37	0.63				0.49	0.51

[A]Sex of harvested animal was not reported.

The number of reported caribou harvested was highest in 2010, however many of the harvested caribou were of unknown sex. The ratio of known sex caribou that were harvested suggested that cows were harvested in slightly higher numbers in 2010 and 2011 (Figure 4). However, the overall ratio across 2009-2011 was 49% bulls and 51% cows.

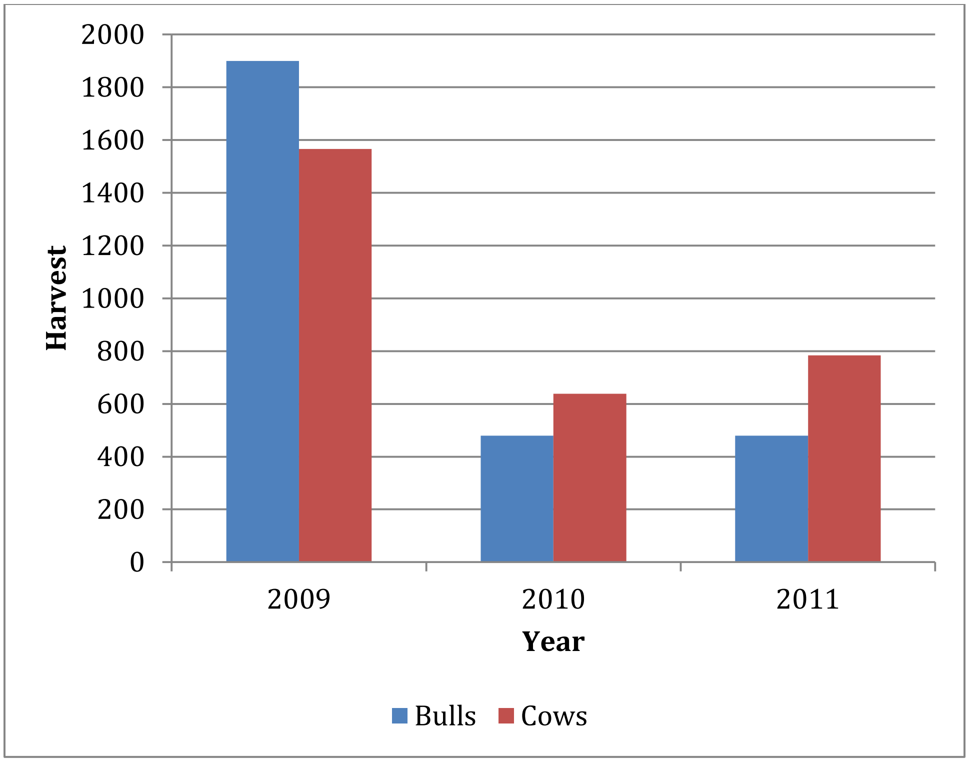

Figure 4: The relative numbers of bulls and cows harvested from the Bluenose-East herd based upon harvest records (Adamczewski et al. 2016; Table 3).

Assessment of Simulation Outcomes

Evaluation using short-term management-based population size levels

The goal of these simulations was to assess the relative risk of various harvest strategies for the herd based on its demographics in 2010. To further this objective, simulations were evaluated in terms of overall population trend, and the proportion of simulations that met specified management and monitoring-based herd population size ranges (Table 5). The proportions of simulations in this context could be interpreted as the relative probability of meeting a given management target.

This current round of simulations used an estimate of total herd size of 122,697 (SE=16,202.2, CI=90,940-154,452, CV=13.21%) from the 2010 post-calving survey as a baseline for the initial population size. Unlike breeding female based estimates, this estimate was for the entire herd including yearlings (calves of the previous year). Therefore, target levels and power were evaluated using this estimate of herd size (and associated precision). To estimate the power to detect change, I assumed the level of precision of herd size estimates from future surveys would be similar to the 2010 survey. I then estimated the difference in herd sizes required to detect change in population size using a two-tailed t-test with a α level of 0.1. In this case, the hypothesis would be a change in population size as opposed to a directional (negative or positive increase). Degrees of freedom for the t-tests were estimated using the formulas of Gasaway et al. (1986).

As discussed later, the t-test is not necessarily the most efficient method to compare population estimates; however, this analysis was mainly intended to provide a general estimate of the power to detect trends which could be used to determine the appropriate intervals for calving ground based population estimates. An alternative is trend analysis from visual surveys of calving grounds. As discussed later, a power analysis on this approach is planned to compare with the t-test based method.

Note that an alternative method to track trend is using estimates of breeding females from the calving ground. This approach may be more powerful since it will be less sensitive to the yearly variation in productivity. However, the main objective of simulations was to evaluate change in overall herd size so therefore this metric was mainly used for evaluation of simulation results.

Table 4: Levels of target populations for management used for simulations based on post calving survey baseline Bluenose-East herd estimate in 2010. Detectability is based upon the assumption that future calving photo surveys have the same level of precision as the 2010 survey. Colors used in graphics for each target management level are also shown.

Management objective	Target herd size range	Comments
Detectable increasing herd size	>167,000	Detectable increase
Potential increase (not detectable)	122,697-167,000	Increase but not statistically detectable
Potential decline (not detectable)	89,500-122,697	Potential decline that is not statistically detectable
Detectable decline	60,000-89,500	Decline becomes detectable
Herd in severe decline (detectable)	<60,000	Bluenose-East Management plan threshold

Another pertinent question for management was the timelines in which the herd might meet target herd sizes and the corresponding intervals in which management strategies should be evaluated. As time progresses, herd size changes, making apparent increases or declines more evident. Therefore, the interval for evaluation of population size (i.e., a spring calving ground survey) was of interest in evaluating management targets as proposed in Table 5. The probabilities of the management targets were therefore evaluated at three, six and nine years which corresponded to possible intervals in which subsequent calving ground surveys might be conducted. These results help determine the optimal monitoring intervals needed to ensure detection of various herd size levels.

Predicted Demographic Trends and Field Based Estimates

A key use of this model is not just predictions in terms of population size but also predictions of field based measurements to further assess herd status. Therefore, I also generated predictions of most of the field-based measurements such as calf-cow ratios and bull-cow ratios. Breeding female population size was also predicted given that it was influenced by both overall herd size and the assumed productivity scenario and level of fecundity.

Of particular importance for bull dominated harvest was the effect of harvesting bulls on the bull-cow ratio. Therefore changes in this metric were a focus of analyses.

RESULTS

I used stacked bar charts that displayed the simulation outcomes in terms of productivity scenarios (Table 1), management targets (Table 4), and monitoring intervals (years until next calving ground survey) for the most applicable simulations. The idea of the bar-charts is to convey the probabilistic nature of the stochastic model outcomes in a graphical fashion. The colours of the stacked hopefully convey the relative risk of each outcome (red=”very high risk” and green=”less risk”).

There is a lot of information displayed when variation in productivity, monitoring interval, population target levels, and harvest levels are considered simultaneously. The stacked bar-charts efficiently summarize the range of simulation outcomes across a range of assumed productivities and monitoring intervals. *While these contain a lot of detail, they can also be viewed with less detail.* Basically, a graph that has a lot of red means that the given scenario has a high risk of rapid decline compared with a graph that is mainly yellow or green. Some combinations of higher calf productivity and low harvest can result in a stable or increasing herd; these could serve as estimators of a sustainable harvest under those conditions. This allows interpretation of risk of management strategies without detailed attention to individual simulation outcomes.

Simulations with No Harvest.

Simulations with no harvest revealed a general increasing trend in herd size under the three year (0.38) and high productivity scenarios (Figure 5). In review, the yellow and light green bars represent decreases and increases that would not be detectable whereas the green and orange/red bars represent detectable increases or decreases. In general, increases would occur under the average productivity scenario but the increases would not be detectable. If productivity was lower then declines would be detected in 50% of simulations in six years. If productivity was high then increases would be detected in 80%

of simulations by year six. One main point to be made here is that productivity levels will greatly influence herd dynamics and therefore productivity needs to be considered in unison with harvest strategies.

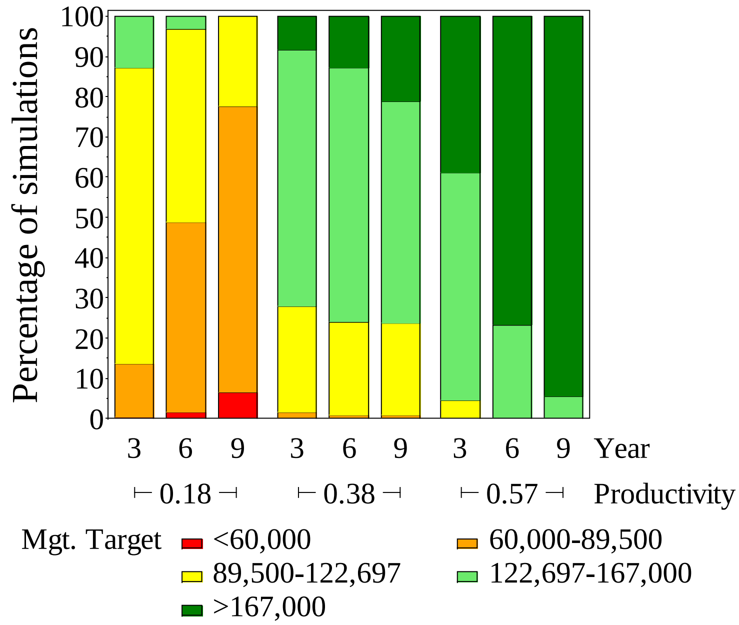

Figure 5: Results of simulations with no harvest (male or female) across three levels of productivity for the Bluenose-East herd in 2010. Each colour on the bar denotes the relative proportion of simulations that resulted in a given range of herd sizes/management targets with the estimates of 52,000 cows and 102,000 caribou as a baseline. Declines that are coloured red and increases that are coloured green are statistically detectable. For these simulations adult female survival was 0.88 since no harvest was simulated. Productivity estimates correspond to productivity scenarios as listed in Table 1.

Harvest with Varying Proportions of Bulls and Cows Harvested

Simulations were first evaluated in terms of the effect of harvest strategies on overall population trend. The three year average productivity simulations were then evaluated further in terms of target management population sizes.

Effect of Harvest on Overall Population Trend.

The effect of harvest on overall population growth rate (λ) depended on the assumed level of productivity, the overall harvest level, and the proportion of bulls in the harvest (Figure 6). Under the high productivity scenario, all levels of harvest resulted in a stable or increasing population size. Under the three year average productivity scenario, the no harvest simulations, or simulations with 75-100 percent bulls resulted in a stable population with a decreasing population size when a lesser proportion of bulls (and higher proportion of cows) was harvested (with harvest level=3,000). All simulations resulted in a declining population under the low productivity scenario.

In summary, evaluation of simulations based on trend suggests that harvest strategies with at least 50% bulls harvested moderate the risk of substantial population decline (Figure 6). Note that the bull only harvest trend was only slightly lower than the no harvest simulations. As noted earlier the model does not simulate the effect of lower proportions of bulls on mating success and productivity and therefore the only effect of harvest is removal of bulls from the population size. For this reason, the bull-cow ratio should also be considered when evaluating harvest strategies that involve mainly harvest of bulls.

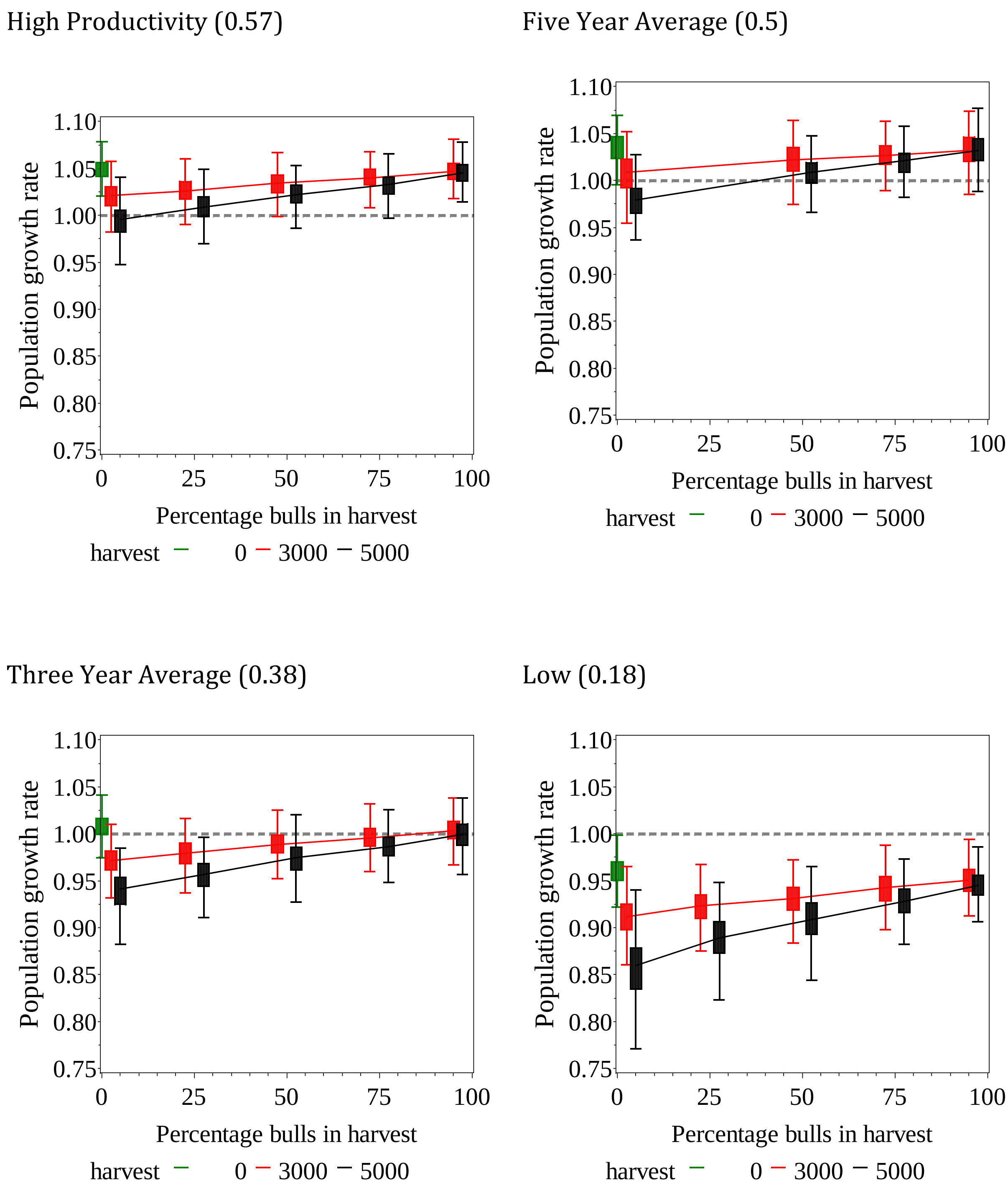

Figure 6: Effect of varying harvest levels and proportion of bulls in harvest as a function of levels of productivity (Table 1) for the Bluenose-East herd in 2010. A population growth rate of one indicating a stable population is given as a reference line. Values below one indicate a decreasing population whereas values above one indicate an increasing population. The boxes around each point indicate the 25th and 75th percentiles of values whereas the limits indicate the range of values.

Evaluation by Future Herd Size

Given that the Bluenose-East population size was relatively large in 2010, it could be argued that the risk of moderate decreases in population size due to harvest can be tolerated. For this reason, it is important to also evaluate simulations in terms of potential future herd sizes under varying harvest strategies.

For harvest levels of 3,000, there was minimal detectable change in population size across all bull harvest levels (Figure 7). If proportions of bulls harvested were lower (34% or less) than declines were detected in 10-20% of simulations by year nine. This would correspond to a herd size of 60-89,500 caribou.

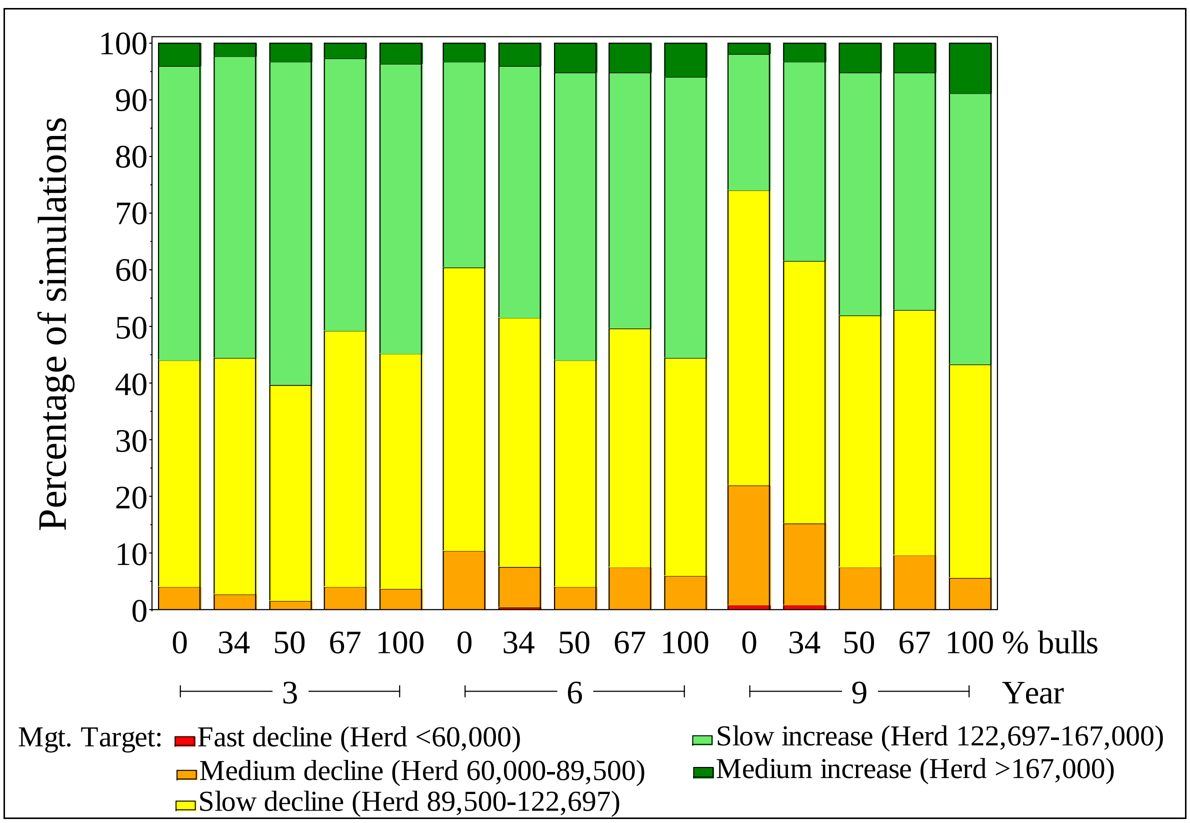

Figure 7: A harvest of 3,000 caribou with varying levels of percentage of bulls harvested as evaluated at three, six and nine years for the three year average productivity scenario for the Bluenose-East herd in 2010. Outcomes that could be statistically detected are green bars (increase) and red bars (decrease). Moderate decreases (orange bars) or increases (yellow bar) could not be detected.

For harvest levels of 5,000, detectable decreases in population size occurred in approximately 20-30% of the simulations when percentage bulls were 0-25% within six years (Figure 8). Within nine years, detectable decreases occurred in 30-60% of simulations unless percent bulls were 67% or more.

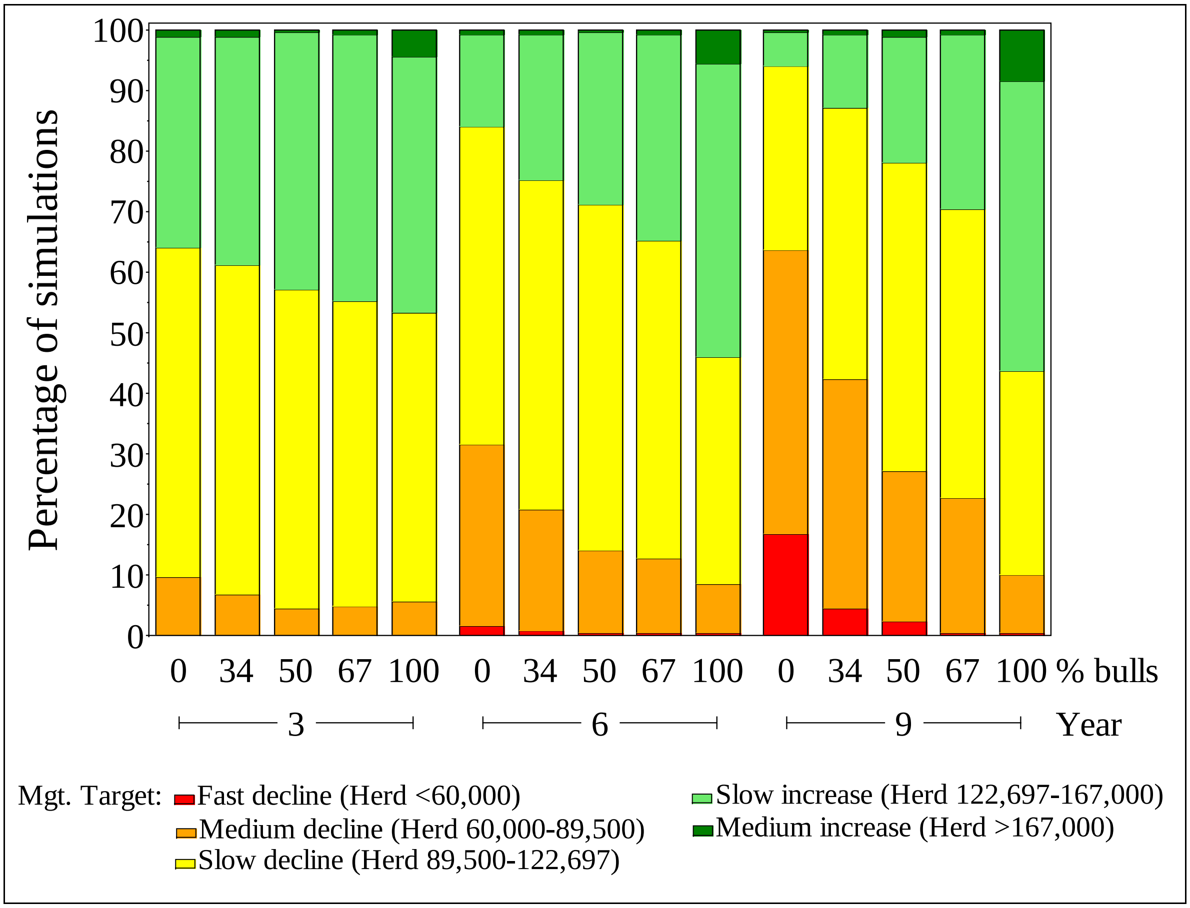

Figure 8: A harvest of 5,000 caribou with varying levels of percentage of bulls harvested as evaluated at three, six and nine years assuming average productivity for the Bluenose-East herd in 2010.

If harvest was increased to 6,000 then detectable decreases occurred in 50% or more of the simulations in nine years when bull harvest was 34% or less (Figure 9). It is important to note that the declines were not detectable in three years, and marginally detectable in six years. In this case, potential larger scale declines were occurring but were not detectable given the levels of precision of calving ground surveys.

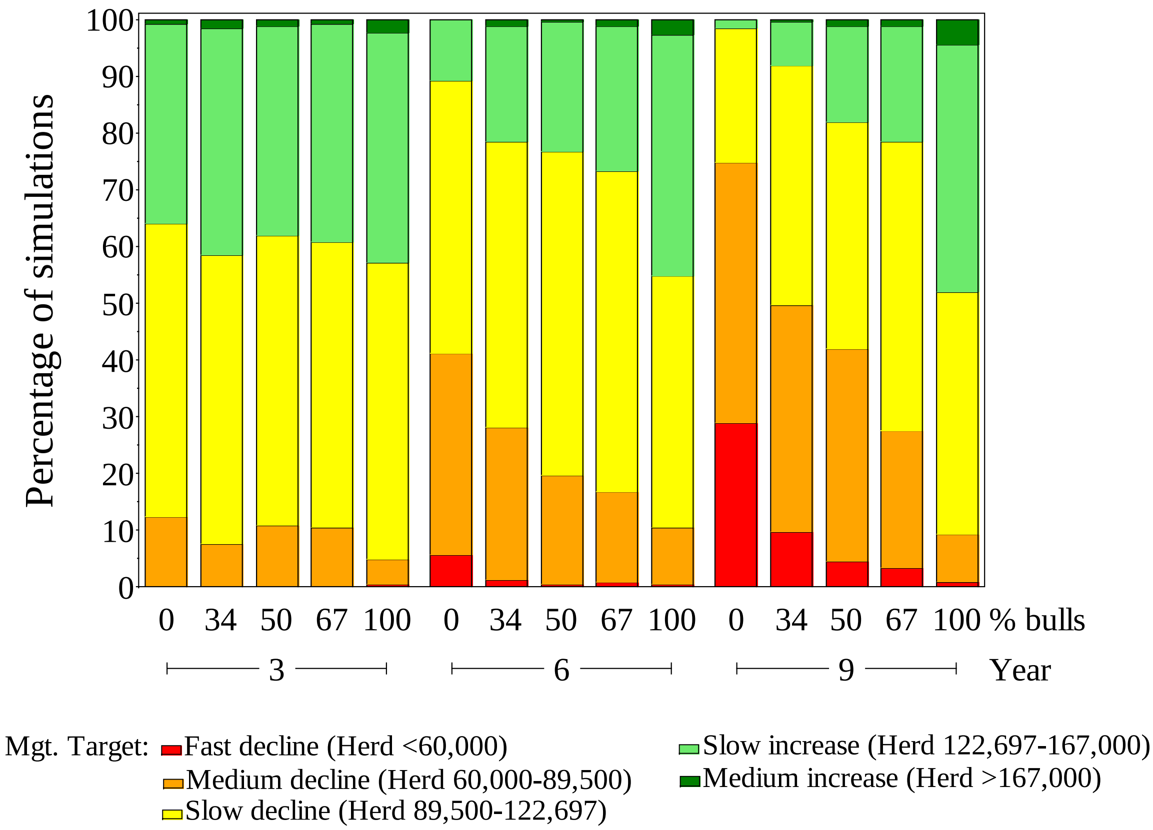

Figure 9: A harvest of 6,000 caribou with varying levels of percentage of bulls harvested as evaluated at three, six and nine years for the Bluenose-East herd in 2010.

These plots were also produced as single bar charts that may be easier to follow, in Appendix 1.

Assessment of bull-cow ratios

As stated earlier, assessment of bull-cow ratios is essential if harvest targets all bulls or a larger proportion of bulls than cows. Figure 10 demonstrates the effect of harvest on fall bull cow ratios as a function of productivity and harvest level for productivity levels at the average of the last three years. Basically, the ratio is not substantially affected when harvest levels are 3,000 even when the majority of the harvest is bulls. When harvest levels are 5,000, bull-cow ratios decrease to low (<0.25) levels within three to four years when the majority of the harvest is bulls.

If all cows are harvested then the ratio will increase whereas it decreases if the harvest is mainly bulls. If an equal number of cows and bulls are harvested then the ratio will stay approximately the same given that the rate of change for the average three year productivity scenario is for only a slight increase in population size. For lower productivity scenarios the general trend is for bull cow ratios to decrease whereas they will increase under higher productivity scenarios.

In terms of management, a threshold bull-cow ratio (i.e., 0.3) should be established as the cut point in which bull harvest should be re-evaluated given possible effects of reduced proportions of bulls on caribou breeding success (Mysterud et al. 2002).

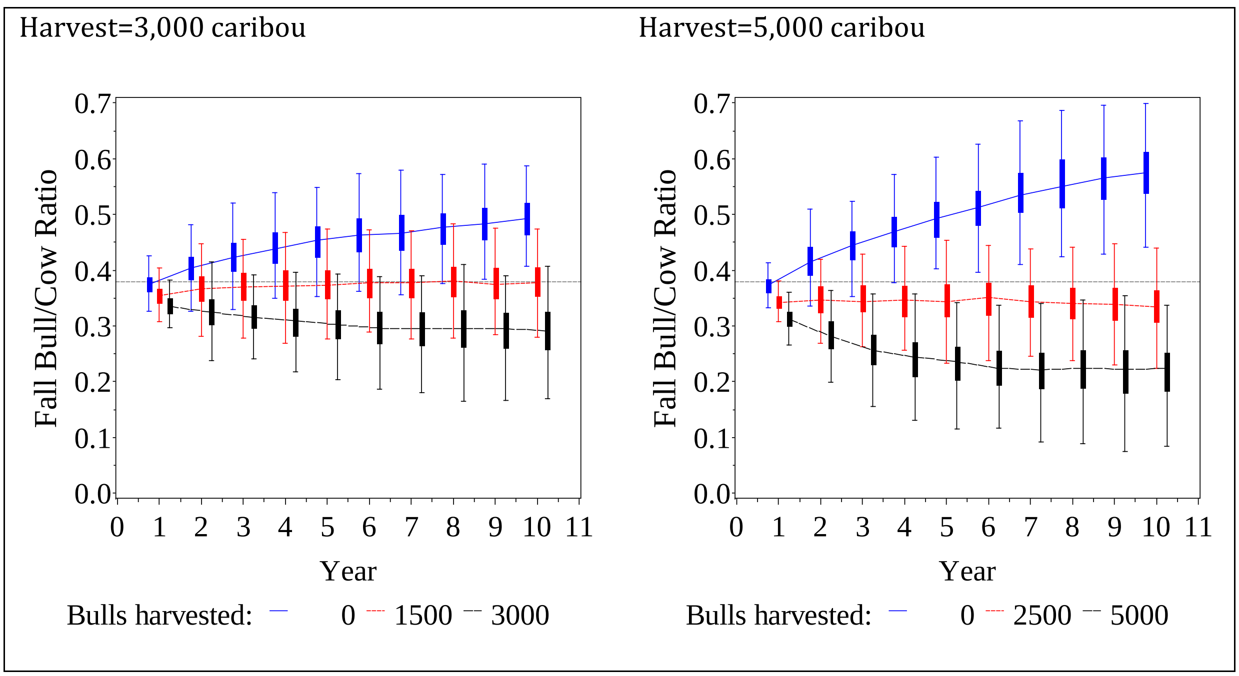

Figure 10: Fall bull cow ratios for the Bluenose-East herd in 2010 with varying levels of bull-only harvest and herd productivity. Simulations assume a bull survival rate of 0.72, with all bulls harvested before composition surveys, and with harvest levels of 3,000 and 5,000 caribou with productivity levels of 0.38 (average of past three years).

DISCUSSION

The main conclusion from the simulations conducted here is that given current levels of productivity and the relatively high cow survival rate assumed, the Bluenose-East herd can sustain moderate (3,000) harvest especially if a substantial proportion of the harvest is comprised of bulls (Figure 7). If harvest is increased to 5,000 then harvest should have a dominant bull component (>50%) to avoid risk of substantial longer-term decline (Figure 8). Even with higher harvest levels, and recent productivity, changes in population size due to harvest would not be detectable until at least six years. A fundamental assumption of this forecast is that productivity will remain at the three year average level. If productivity is lower (as in 2012) then herd size will be more influenced by harvest leading to more detectable declines. If cow survival rates were substantially lower (see for example Boulanger et al. 2014, 2016) then the herd might have a declining natural trend with no harvest and a very careful approach to harvest management would be needed. For this reason, adaptive adjustment of harvest levels with more recent information about productivity, cow survival rates and overall herd trend is essential.

The following points should be also considered when interpreting the simulations in this report.

- *This model does not simulate any effects of reduced breeding success based on bull-cow ratios.* Given this, threshold levels of bull-cow ratios should be also established to ensure reasonable sex ratios as discussed in Mysterud et al. (2002). The model can generate predicted bull-cow ratios that can then be used to evaluate the relative risk of male dominated harvest strategies to the overall population. As mentioned earlier, power analyses can be used to determine the relative power to detect a threshold bull-cow ratio for a given harvest sex ratio, productivity, and management regime.

- *This model assumes similar survival rates and demography for the Bluenose-East and Bathurst herds, thus an assumed cow survival rate of 88%. Better estimates of survival from collared caribou of the Bluenose-East herd or from OLS modeling of the herd would help ensure these simulations are applicable*. Presently (2012), collar databases from the Bluenose-East herd were not suitable for survival analysis given the large number of caribou with unknown fates. Better tracking of fates would allow direct estimates of survival from the Bluenose-East herd.

- *Better estimates of true harvest level are essential to help refine herd recovery scenarios and determine the relative impact of harvest on adult female survival.* It would be possible to use harvest as a direct model input to allow better assessment of harvest levels on herd recovery. In this case, model runs could be focused on exact harvest levels rather than being run across a wide range of potential harvest levels. Basically, reporting of harvest rates is one of the fundamental requirements of an adaptive management program. Harvest levels should be a model input rather than a model estimate.

- *The simulations assume that natural mortality rates have remained relatively constant.* If predation has also increased over time, or if predators took the same number of caribou each year as the population declined, then the adult female survival estimation without hunting will be less than 88%. This will result in reduced population vigor and a higher likelihood of population decline for each of the scenarios. The only way to test this assumption would be to substantially increase the number of collared caribou to allow better estimates of natural survival or to use the OLS model to generate adult survival estimates (see Boulanger et al. 2014, 2016). In addition, better estimates of harvest would allow a better assessment of the proportional impact of hunting on the herd. This general assumption, and its implication, further argues for an adaptive management approach in which simulation runs and population targets are incrementally re-evaluated as more data become available.

A survey in June 2013 documented a substantial decline in Bluenose-East herd size between 2010 and 2013 (Boulanger et al 2014) and analyses estimated natural adult female survival at 0.74 in 2013, assuming an annual harvest of 4,000 caribou and 65% cows (Boulanger et al 2014). A further survey in June 2015 (Boulanger et al. 2016) indicated that the decline 2010-2013 had accelerated between 2013 and 2015, underscoring the need for a very careful approach to harvest of this herd. Therefore, the simulations in this paper will not directly apply to Bluenose-East demography and ability to sustain harvest after 2010. A more general approach to deterministic modeling of harvest of various sizes and sex ratios in barren-ground caribou herds with a range of cow survival rates and calf productivity levels was reported by Boulanger and Adamczewski (2016) with a case study of the Bluenose-East herd in 2013. We suggest readers refer to this report for updated information on Bluenose-East trend and harvest recommendations appropriate to the herd's demographics.

- *Power analyses demonstrate limited power to detect moderate changes in herd size and therefore herd status should be evaluated also using productivity and survival rate estimates.* This also demonstrates that herd size along with productivity and adult survival should be simultaneously used to evaluate herd status through the framework of a population model. Model based methods (Boulanger et al 2011) can help interpret calf-cow ratios and bull-cow ratios that are influenced by many demographic factors. Note that the OLS model will generate a predicted population size as new data such as calf-cow ratios are produced. The model in this exercise generates predictions of all field based estimates. Power analyses can be used to further optimize appropriate intervals to sample for composition or sex ratio based upon assumed demographic/management scenarios.

- *Biological variation creates uncertainty in many outcomes and recovery scenarios are best interpreted as probabilities rather than estimated future population sizes.* It should be evident that estimation of exact future population sizes is not possible given uncertainty in various current aspects of herd demography.

- *The modeling results could be used to assess the size of a sustainable harvest if calf productivity improves.* In the past, herds growing rapidly were able to tolerate a significant harvest and still increase. Unfortunately, caribou and reindeer herds are for the most part declining across the north (Festa-Bianchet et al. 2011, Vors and Boyce 2009), which suggests that high productivity is not very likely in the near future.

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APPENDIX

The charts below detail simulation outcomes using simplified bar charts that may be easier to understand than the more complex graphics shown earlier in the report.

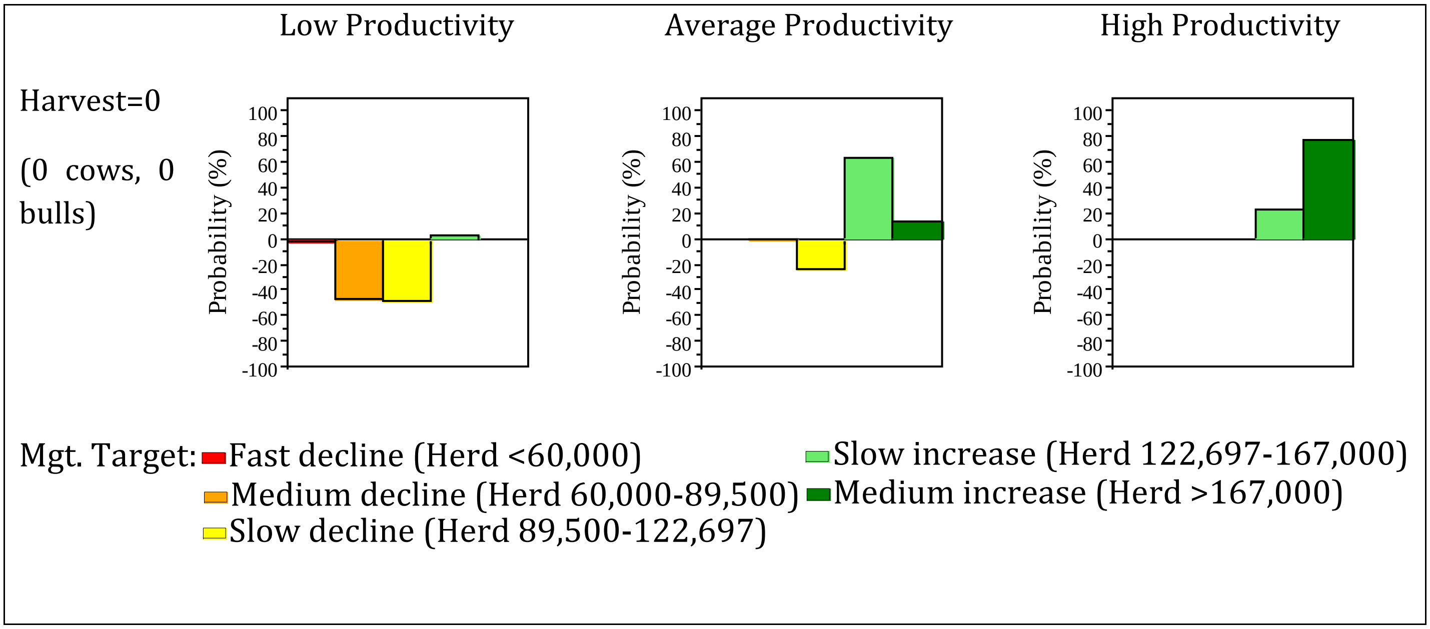

Figure 11: Simulation outcomes under no harvest evaluated at 6 years for the Bluenose-East herd in 2010.

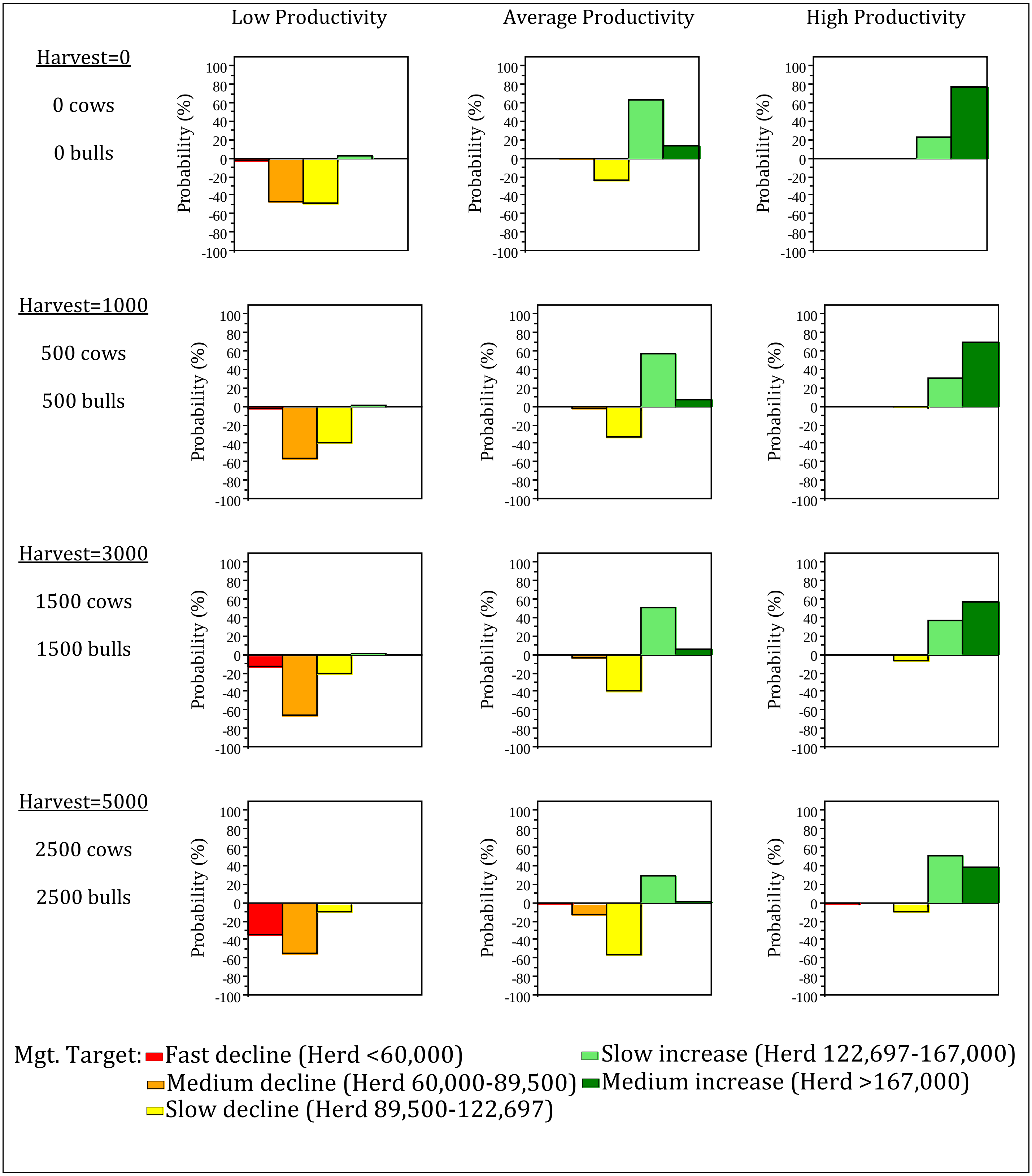

Figure 12: Simulation outcomes under a 50/50 harvest sex ratio evaluated at six years for the Bluenose-East herd in 2010.

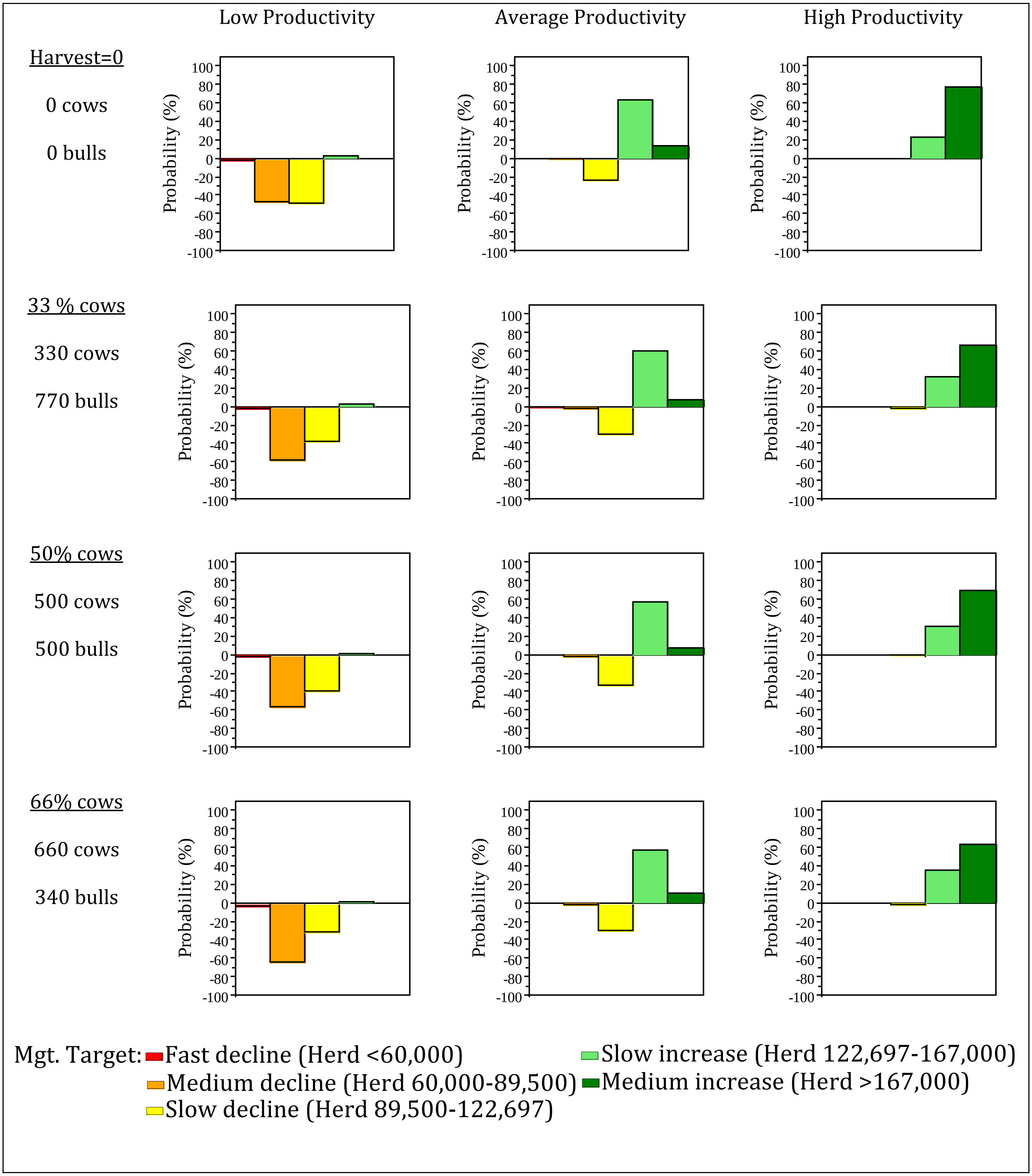

Figure 13: Simulation outcomes under a harvest level of 1,000 and various harvest sex ratios evaluated at six years for the Bluenose-East herd in 2010.

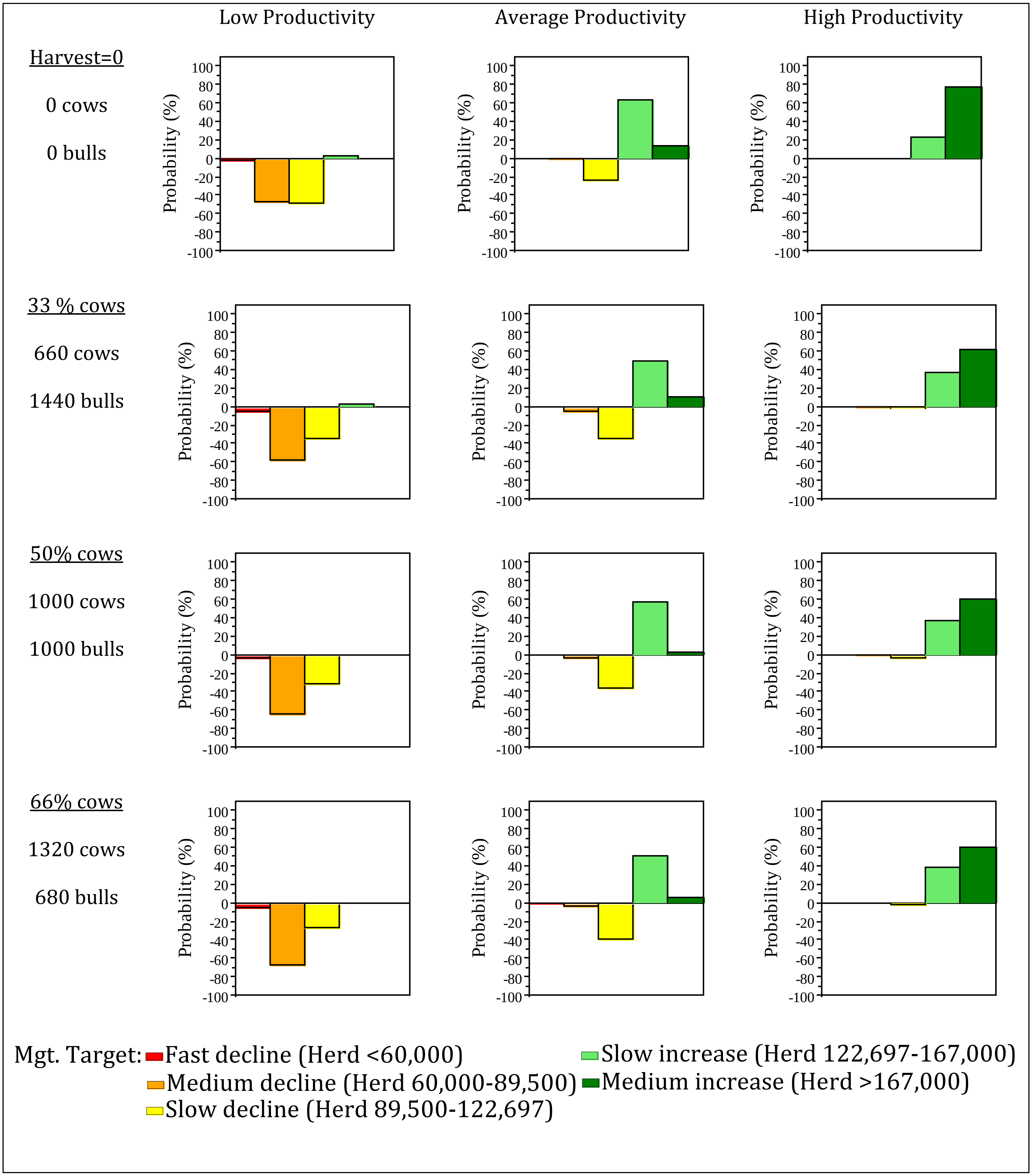

Figure 14: Simulation outcomes under a harvest level of 2,000 and various harvest sex ratios evaluated at six years for the Bluenose-East herd in 2010.

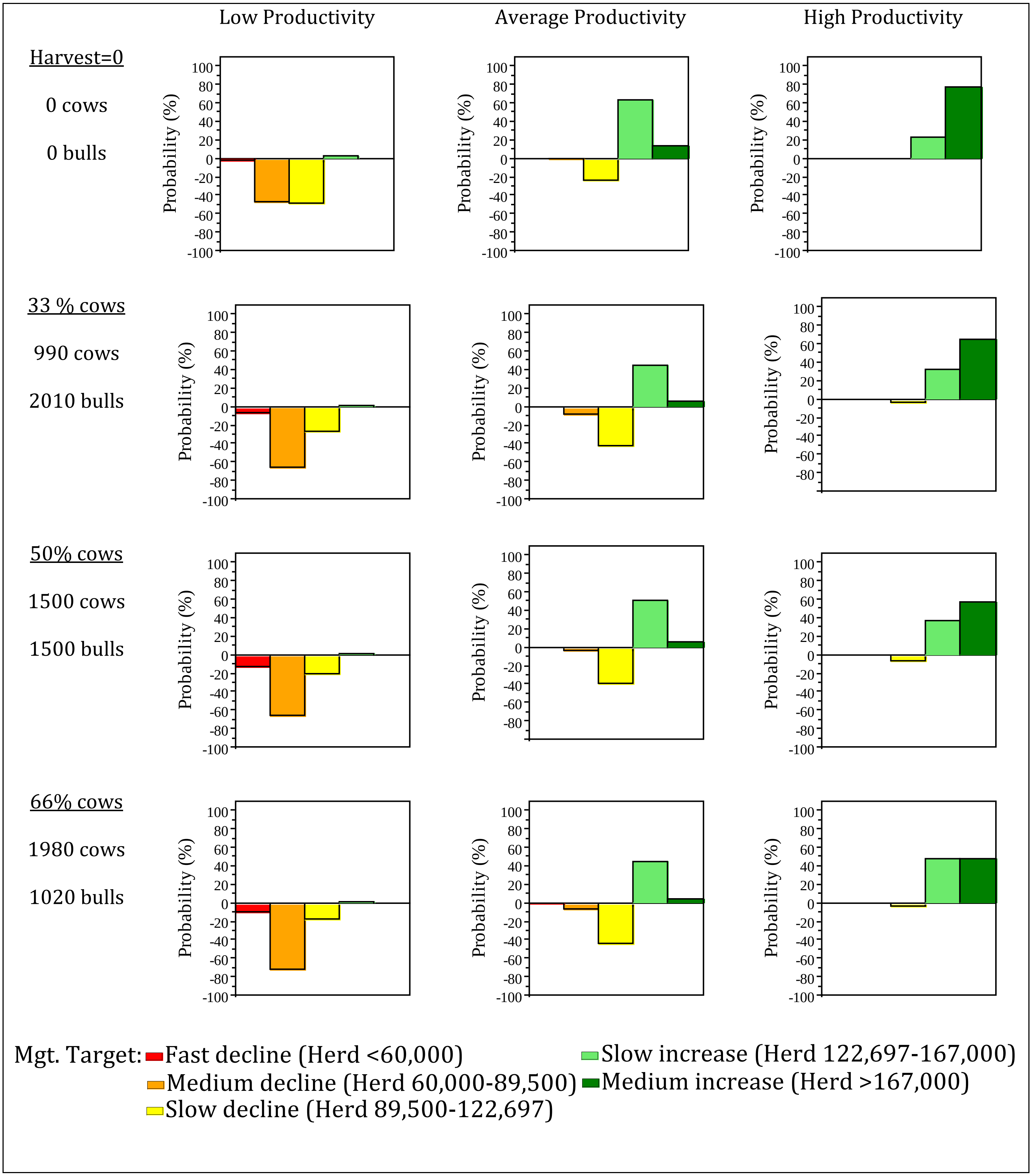

Figure 15: Simulation outcomes under a harvest level of 3,000 and various harvest sex ratios evaluated at six years for the Bluenose-East herd in 2010.

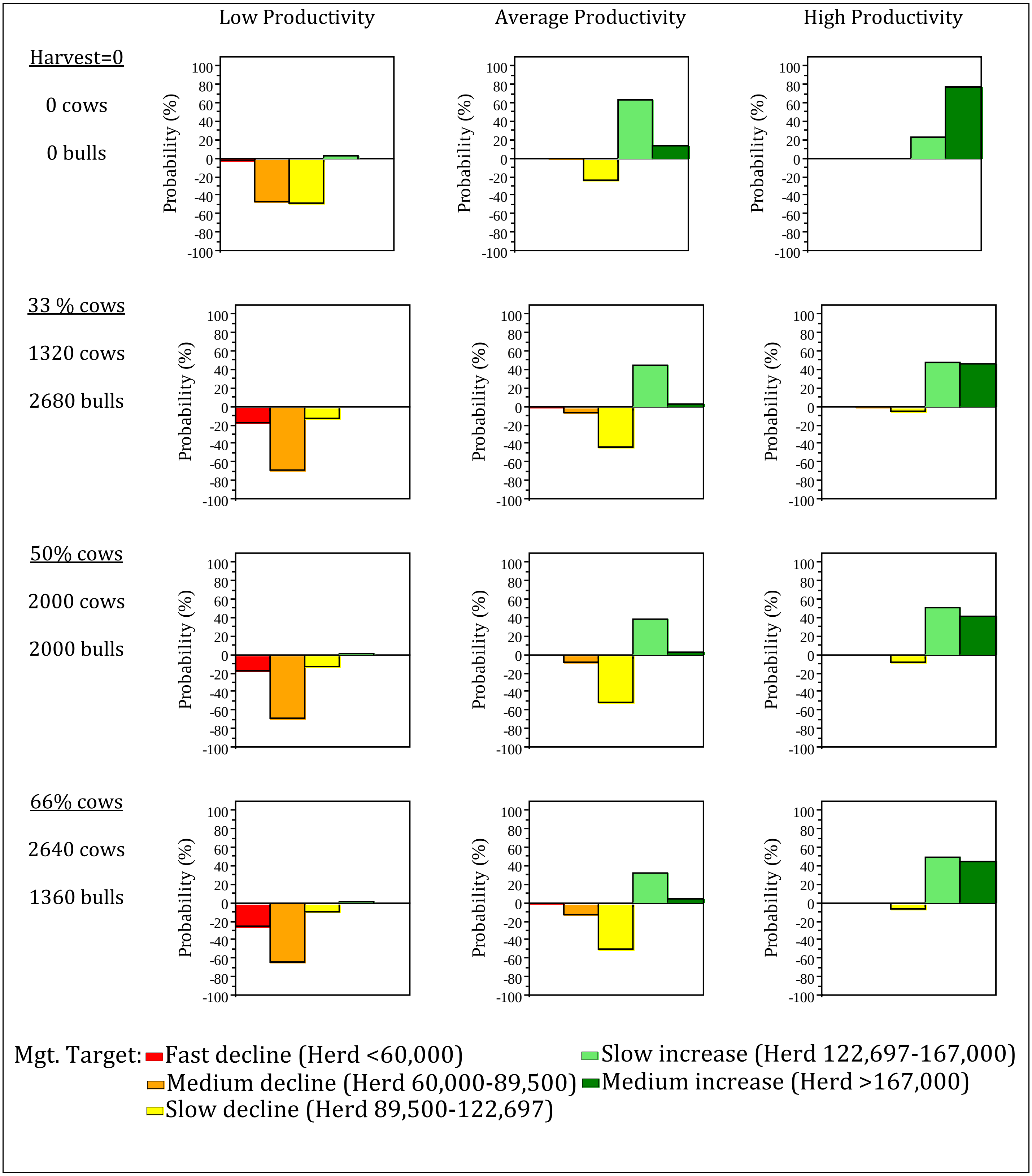

Figure 16: Simulation outcomes under a harvest level of 4,000 and various harvest sex ratios evaluated at six years for the Bluenose-East herd in 2010.

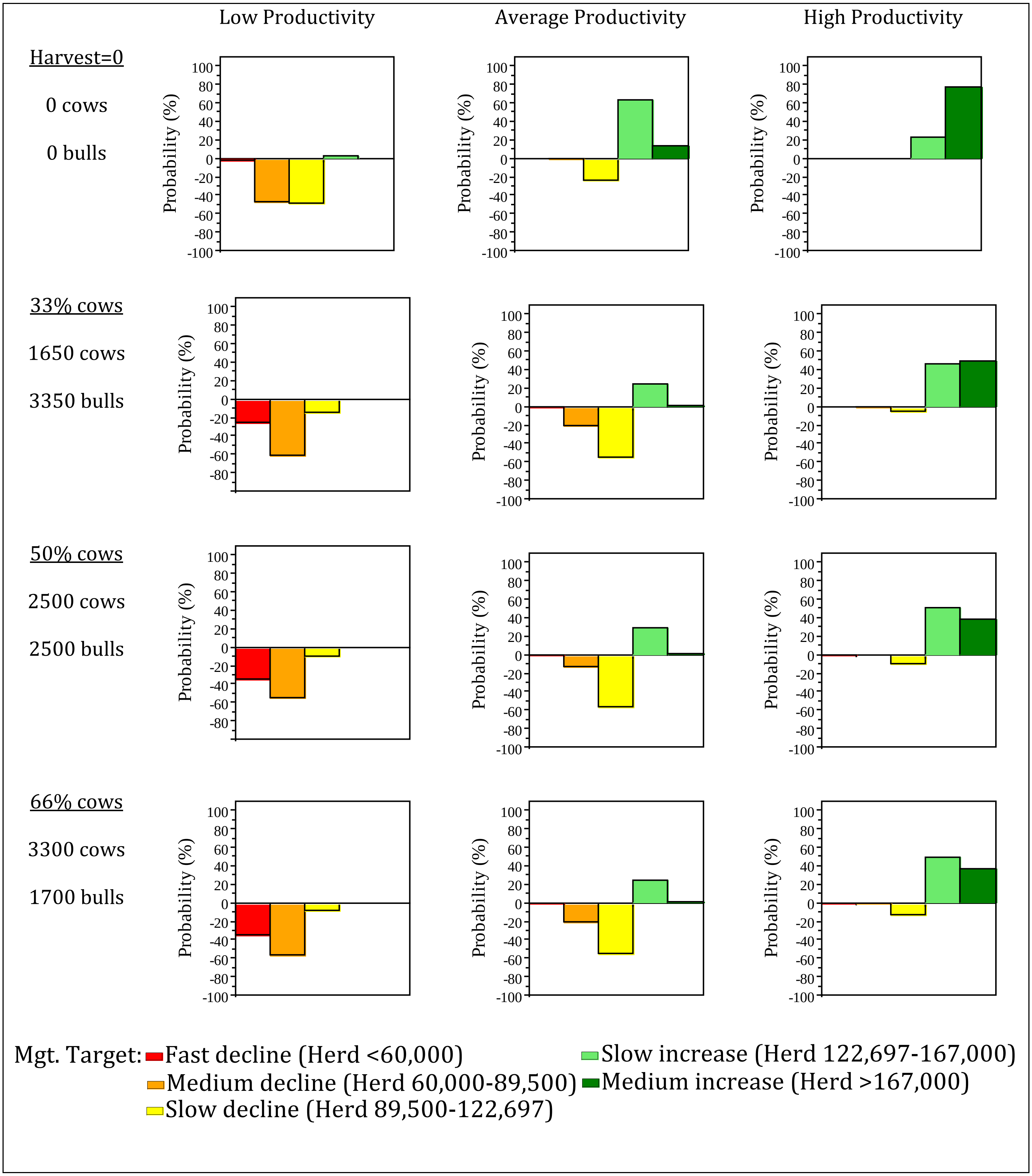

Figure 17: Simulation outcomes under a harvest level of 5,000 and various harvest sex ratios evaluated at six years for the Bluenose-East herd in 2010.

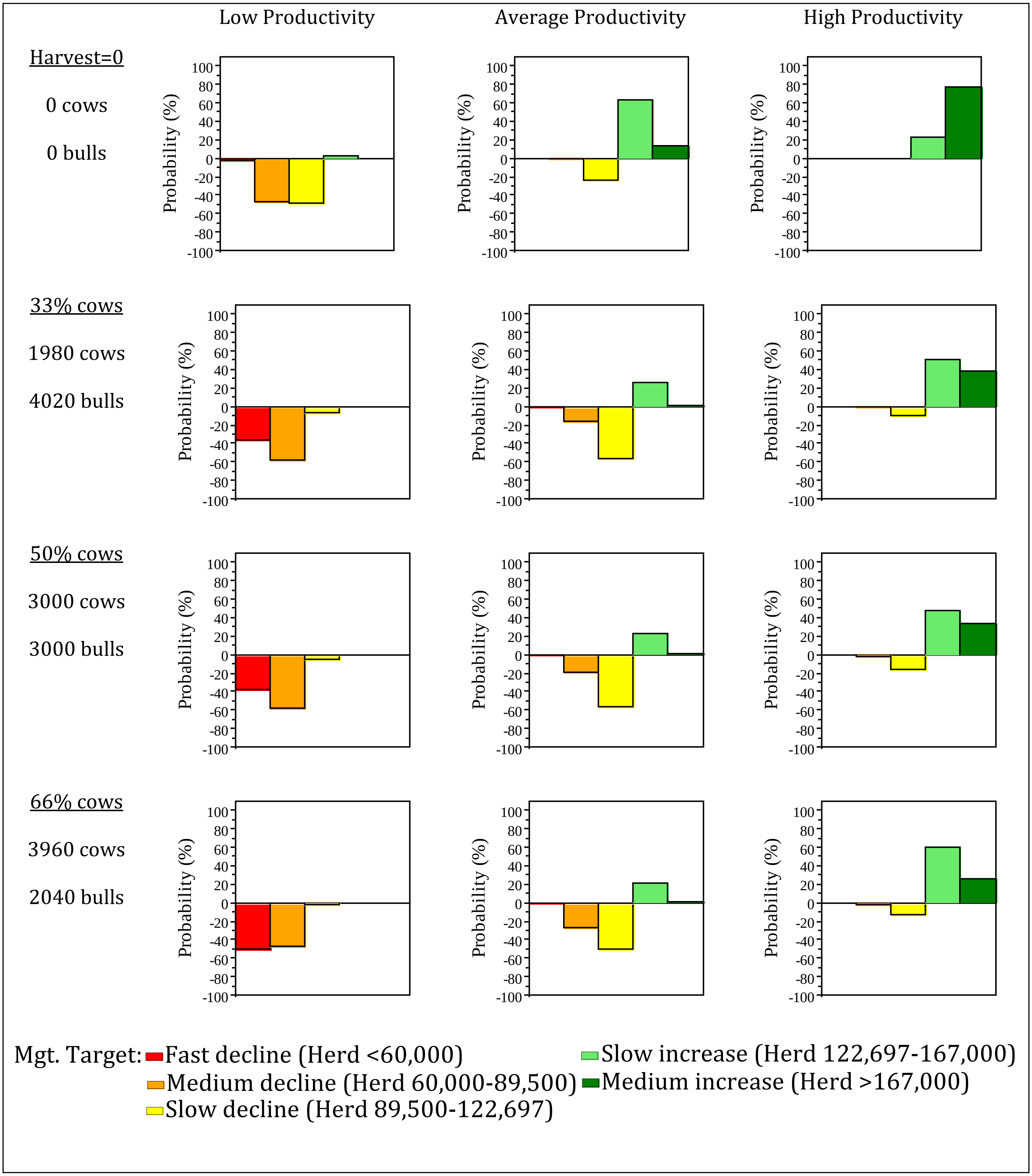

Figure 18: Simulation outcomes under a harvest level of 6,000 and various harvest sex ratios evaluated at six years for the Bluenose-East herd in 2010.