Exploration of harvest strategies for the Bluenose East caribou herd using post-calving based estimates of herd size

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1. Introduction

In this report I explore scenarios for harvest with the Bluenose East herd under varying levels of harvest and management regimes. This work uses the stochastic population model as developed by Boulanger and Gunn (2007) and Boulanger et al. (2010) to simulate variation in demographic parameters in caribou herds. This work updates a previous report by using estimates of herd size from post calving surveys (Adamczewski et al 2012) rather than extrapolated herd size estimates from calving ground surveys as a basis for simulations.

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 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.

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2. 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.

2.1. 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 2 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. Recent calf-cow ratios for the Bluenose herd suggest a range from 0.48 in 2007 to 0.272 in 2012 (Figure 1).

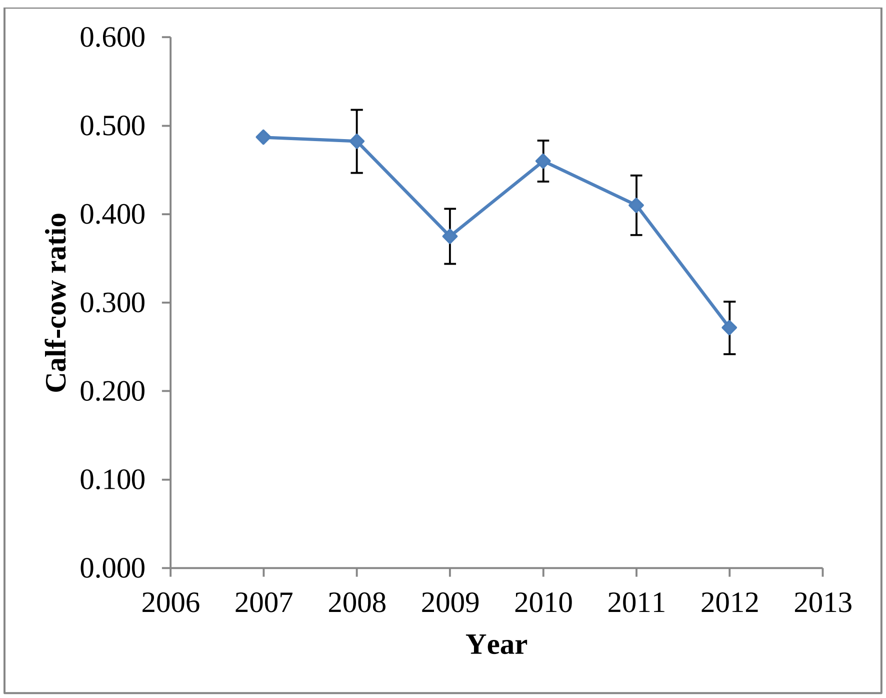

Figure 1: Calf-cow ratios for the Bluenose East herd from spring composition surveys.

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 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 was a primary focus of simulations.

Table 1: Productivity scenarios considered in simulations. 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 to 0.5. Therefore, yearly variation in productivity was considered during simulations.

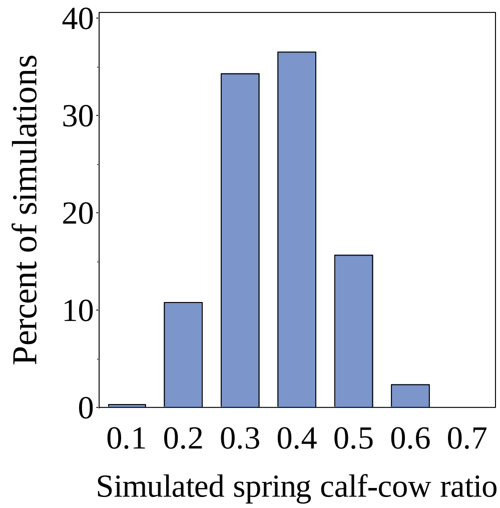

Figure 2: Distributions of calf cow ratios from simulations with the three year average productivity (2010-2)

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.

2.2. Values for demographic parameters

Adult survival values were not available for the Bluenose East caribou herd 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 (2010). Boulanger et al. (2010) 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. (2010). 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

2.3. Initial population sizes for simulations

This current round of simulations used an estimate of total herd size of 122,697 (SE=16202.2, CI=90,940-154,452, CV=13.21%) from the 2010 post calving survey as a baseline for population size (Adamczewski et al. 2012). 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. 2012). The difference in this case was due to the inclusion of bulls and yearlings that may have not 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 estimate 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. 2012). 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 was higher (Figure 3). This difference was presumably due to the fact that bulls were potentially undercounted on the calving ground (Adamczewski et al. 2012). 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.

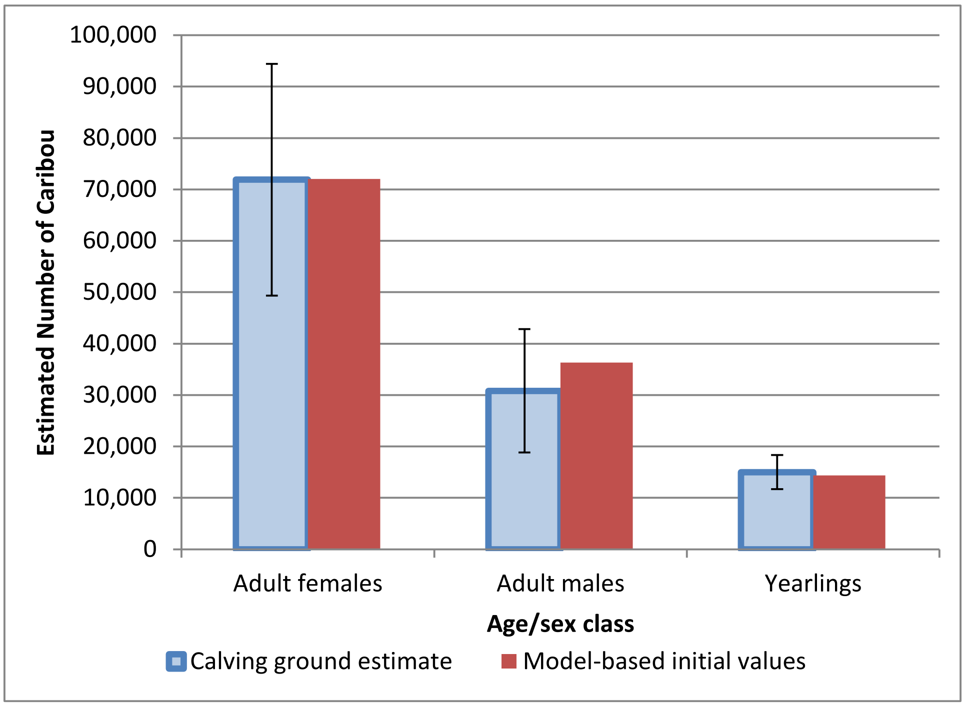

Figure 3: Estimated numbers of adult cows, females, and yearlings in the Bluenose East herd from calving ground surveys, fall composition surveys, and assumed pregnancy rates (Table 3)

2.4. 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 cows in mid-winter and this factor was considered when producing simulated fall bull-cow ratios. Actual harvest levels were based upon reported levels for fall and winter (Table 3). On average, 413.3 and 2303 caribou were harvested in the fall and winter for an overall average annual harvest of 3130. 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 3000 and 5000 caribou were considered in simulations.

Table 3: Harvest levels reported for the Bluenose East herd.

Year	Fall				Winter				Total (Fall + winter)		
	Bull	Cow	Unk[A]	Total	Bull	Cow	Unk	Total	All	bulls	cows
2009	1056	0		1056	844	1567		2410	3466	1900	1567
2010				0	480	638	1800	2918	2918	480	638
2011	59	71	54	184	420	713	449	1582	1766	479	784
Sum	1115	71	54	1240	1744	2918	2249	6910	8150	2859	2989
Ave	371.7	23.7	18.0	413.3	581.2	972.5	749.7	2303.3	2716.7	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 (Figure 4). The ratio of known sex caribou that were harvested suggested that cows were harvested in slightly higher numbers in 2010 and 2011. However, the overall ratio across 2009-11 was 49% bulls and 51% cows (Table 4).

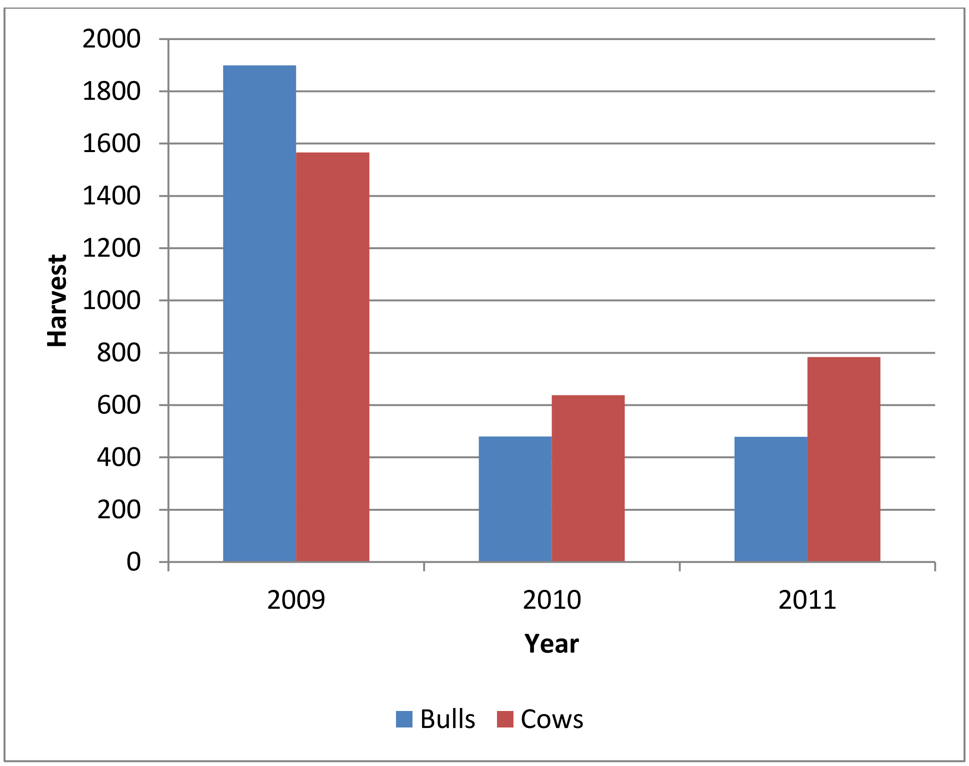

Figure 4: The relative numbers of bulls and cows harvested based upon harvest records (Table 4)

2.5. Assessment of simulation outcomes

2.5.1. Evaluation using short-term management-based population size levels

The goal of these simulations was to assess the relative risk of various harvest strategies. 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=16202.2, 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 2-tailed t-test with an 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 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 herd estimate. Detectability is based upon the assumption that future spring 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	The Bluenose East Mgt 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, the herd size changes therefore 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 3, 6, and 9 years which correspond to possible intervals in which subsequent calving ground surveys might be conducted. These result help determine the optimal monitoring intervals needed to ensure detection of various herd size levels.

2.6. 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.

3. 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 colors 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 harvest 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 So, this allows interpretation of risk of management strategies without detailed attention to individual simulation outcomes.

3.1. 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 than declines would be detected in 50% of simulations in 6 years. If productivity was high then increases would be detected in 80% of simulations by year 6. 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.

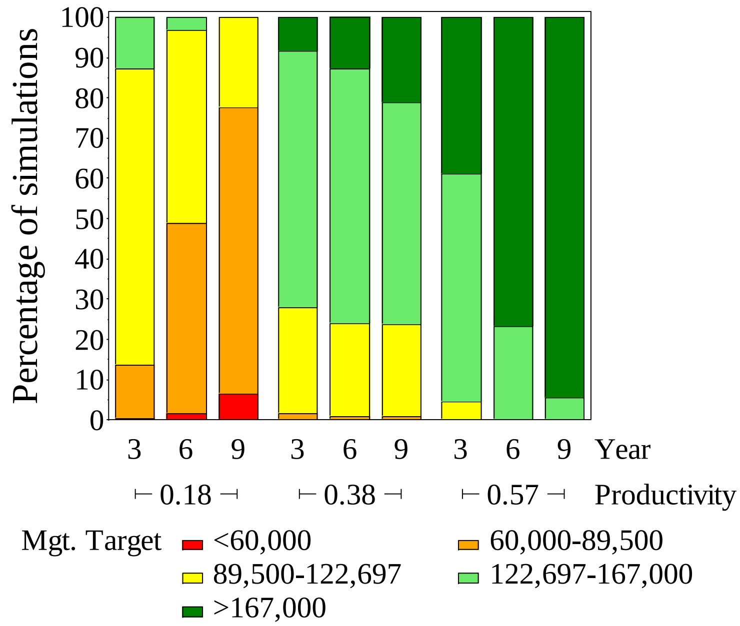

Figure 5: Results of simulations with no harvest (male or female) across three levels of productivity. Each color on the bar denotes the relative proportion of simulations that resulted in a given range of herd sizes/management targets with the estimates of 52000 cows and 102000 caribou as a baseline. Declines that are colored red and increases that are colored 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.

3.2. Harvest with vary 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.

3.3. 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 to 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=3000). All simulations resulted in a declining population under the low productivity scenario.

In summary, evaluation of simulations based on trend suggest 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.

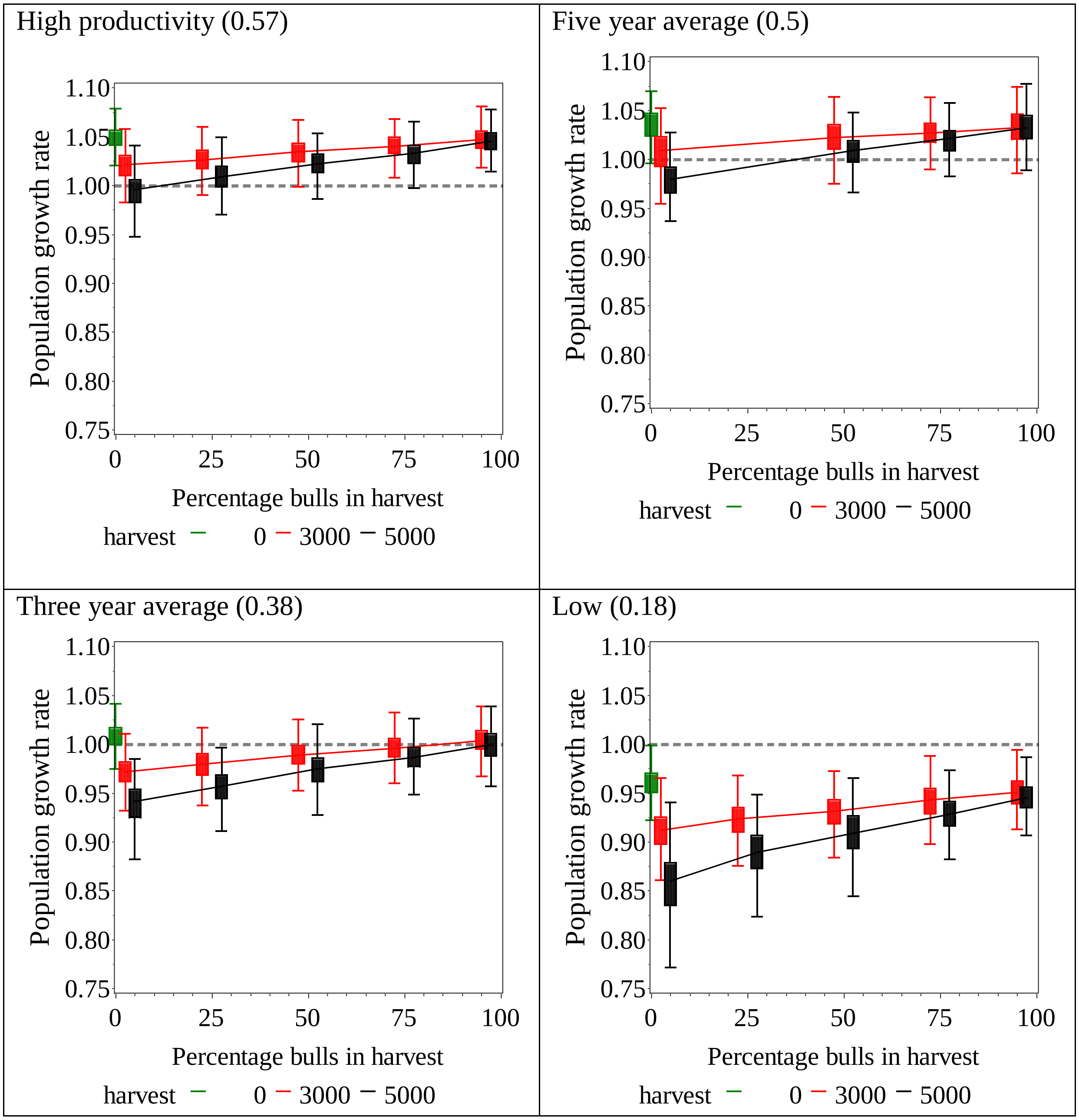

Figure 6:   Effect of varying harvest levels and proportion of bulls in harvest as a function of levels of productivity (Table 1).   A population growth rate of 1 indicating a stable population is given as a reference line. Values below 1 indicate a decreasing population whereas values above 1 indicate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

3.4. Evaluation by future herd size

Given that the Bluenose East population size is relatively large 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 3000, minimal detectable change in population size across all bull harvest levels (Figure 7). If proportions of bulls harvested was lower (34% or less) than declines were detected in 10-20% of simulations by year 9. This would correspond to a herd size of 60-89,500 caribou.

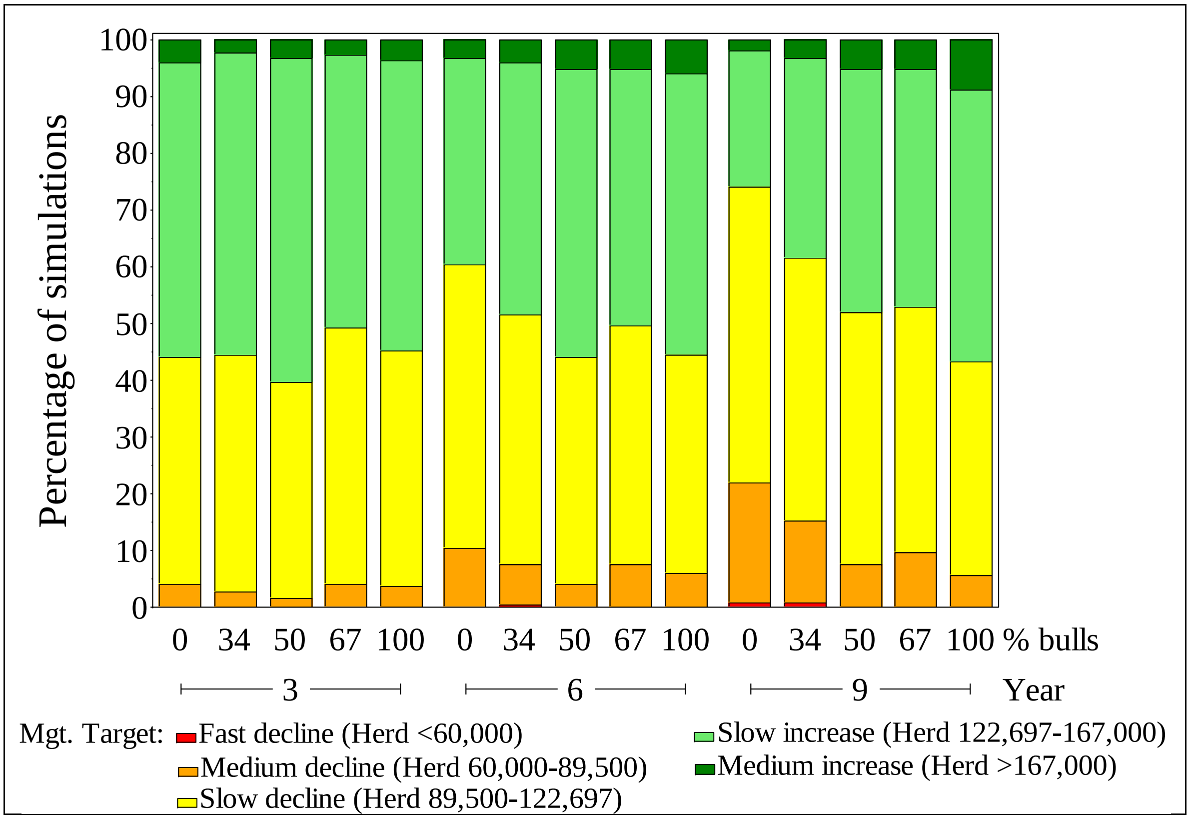

Figure 7: A harvest of 3000 caribou with varying levels of percentage of bulls harvested as evaluated at 3, 6, and 9 years for the three year average productivity scenario. Outcomes that could be statistically detected are green bars (increase) and red bars (decrease). Moderate decreases (orange bars) or increases (yellow bar) could not be detected.

For harvest levels of 5000, detectable decreases in population size occurred in approximately 20-30% of the simulations when percentage bulls were 0-25% within 6 years (Figure 8). Within 9 years, detectable decreases occurred in 30-60% of simulations unless percent bulls was 67% or more.

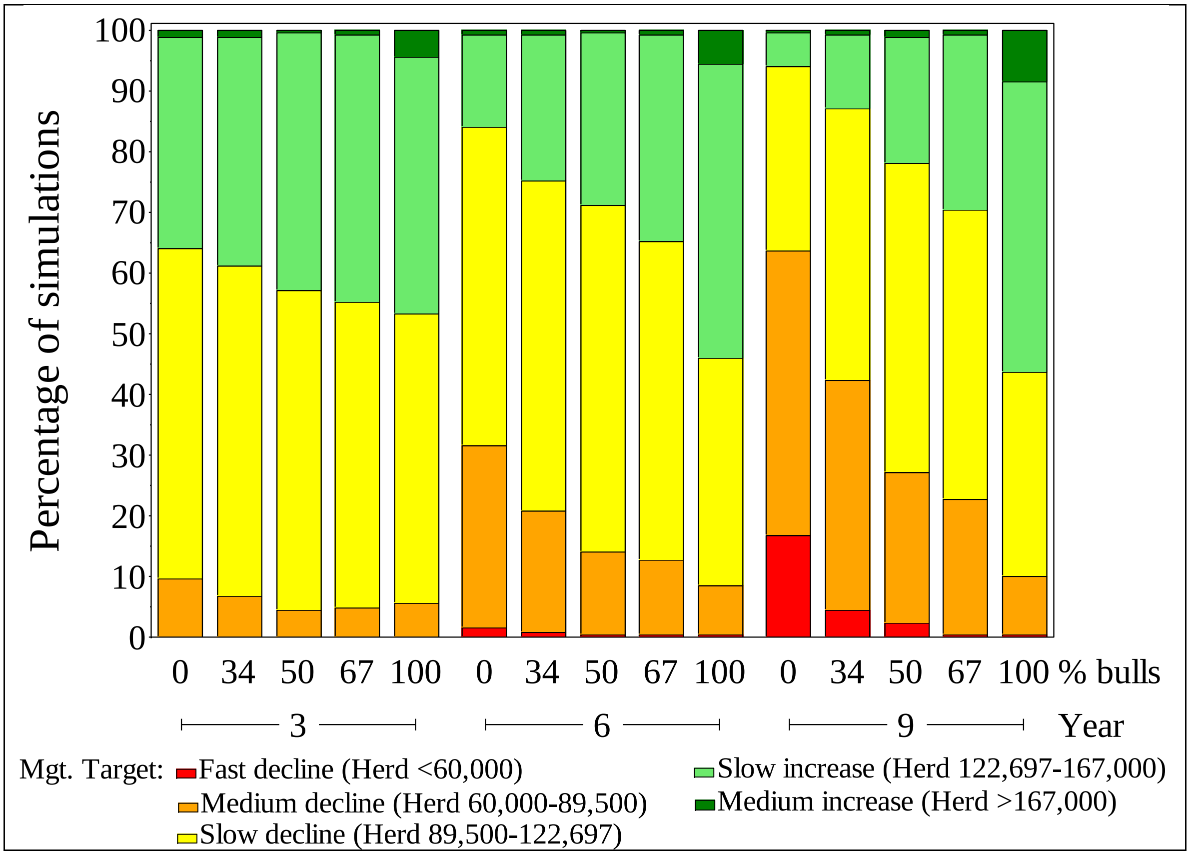

Figure 8: A harvest of 5000 caribou with varying levels of percentage of bulls harvested as evaluated at 3, 6, and 9 years assuming average productivity.

If harvest was increased to 6000 then detectable decreases occurred in 50% or more of the simulations in 9 years when bull harvest was 34% or less (Figure 9). It is important to note that the declines were not detectable in 3 years, and marginally detectable in 6 years. In this case, potential larger scale declines were occurring but were not detectable given the levels of precision of calving ground surveys.

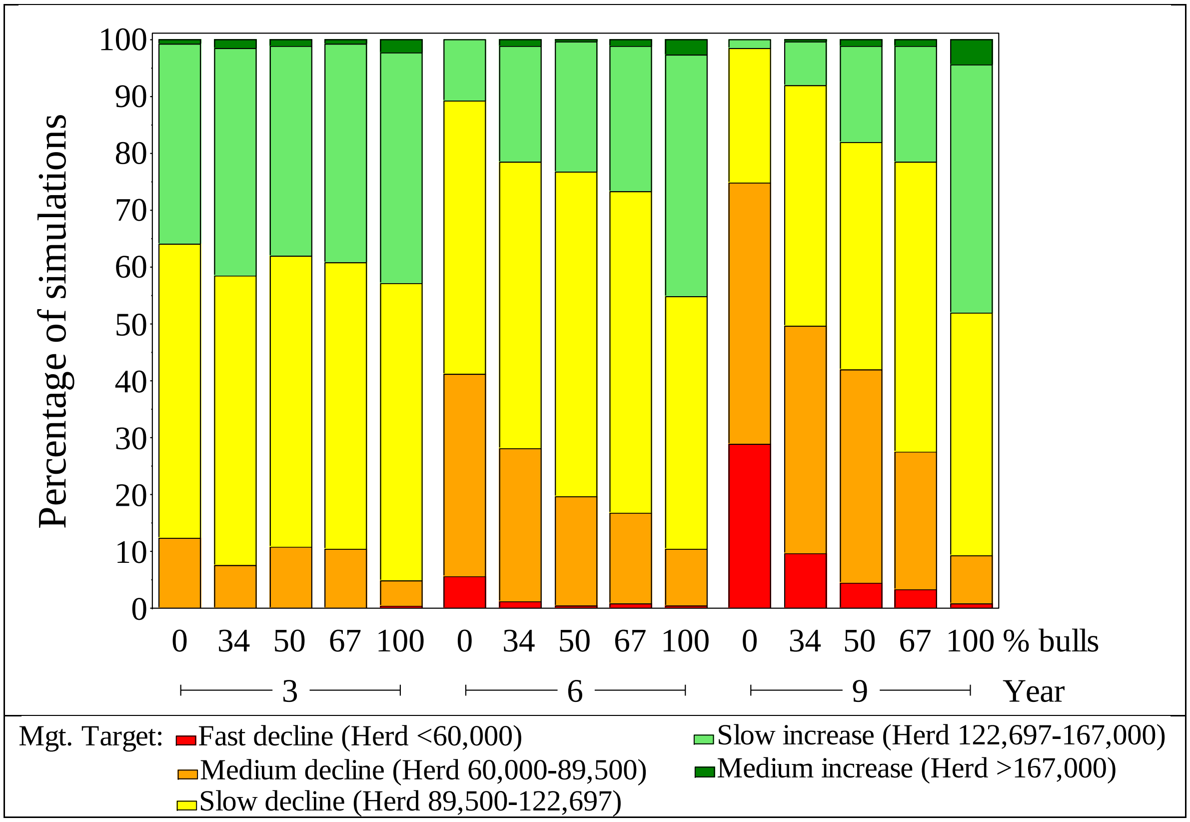

Figure 9: A harvest of 6000 caribou with varying levels of percentage of bulls harvested as evaluated at 3, 6, and 9 years.

These plots were also produced as single bar charts for a plain-language summary as shown in Appendix 1.

3.4.1. 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 ratio as a function of productivity and harvest level for productivity levels at the average of the last 3 years. Basically, the ratio is not substantially affected when harvest levels are 3000 even when the majority of the harvest is bulls. When harvest levels are 5000, bull-cow ratios decrease to low (<0.25) levels within 3-4 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 3 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 likely effects of reduced proportions of bulls on caribou breeding success (Mysterud et al. 2002).

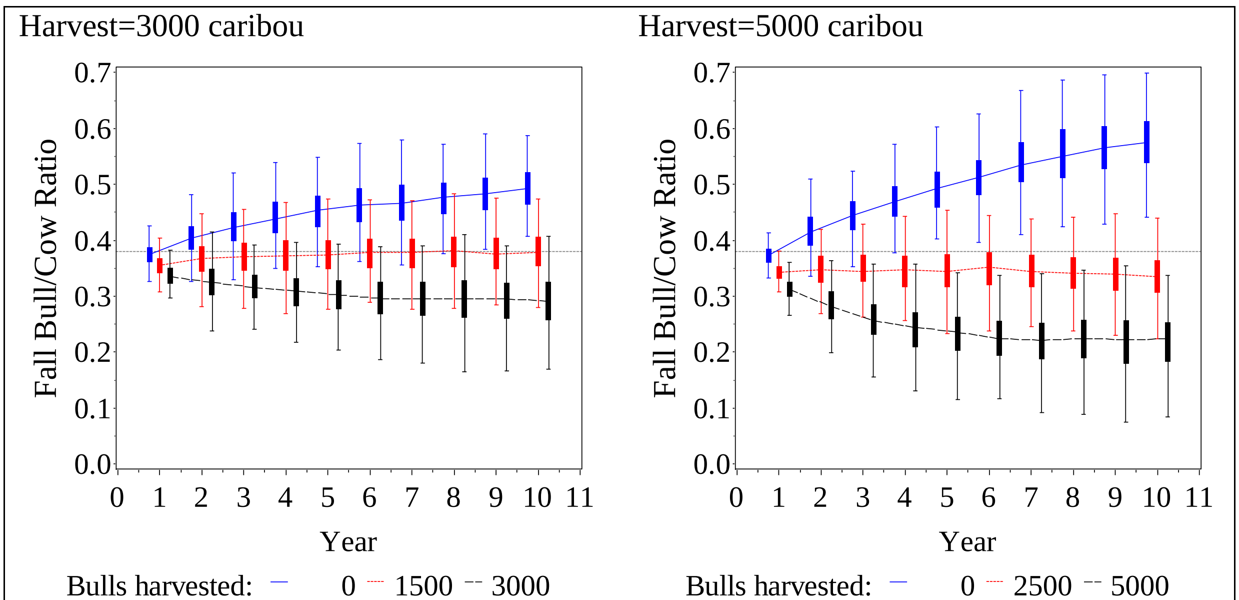

Figure 10: Fall bull cow ratios with varying levels of bull-only harvest and herd productivity assuming a bull survival rate of 0.72 and with all bulls harvested BEFORE comp surveys with harvest levels of 3000 and 5000 caribou with productivity levels of 0.38 (average of past 3 years).

4. Discussion

The main conclusion from simulations is that given current levels of productivity, the Bluenose herd can sustain moderate (3000) harvest especially if a proportion of the harvest is comprised of bulls (Figure 7). If harvest is increased to 5000 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 6 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. For this reason, adaptive adjustment of harvest levels with more recent information about productivity 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 herd. Better estimates of survival from collared caribou of the Bluenose East herd would help ensure these simulations are applicable*. Presently, collar databases from the Bluenose East herd are 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 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 that 0.88. 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. 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 becomes available.

- *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 2010) can help interpret calf-cow ratios, 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 are for the most part declining, which suggests that high productivity is not very likely in the near future.

5. Literature cited

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6. Appendix

The charts below detail simulation outcomes using a simplified bar chart. These will be used for a plain language summary

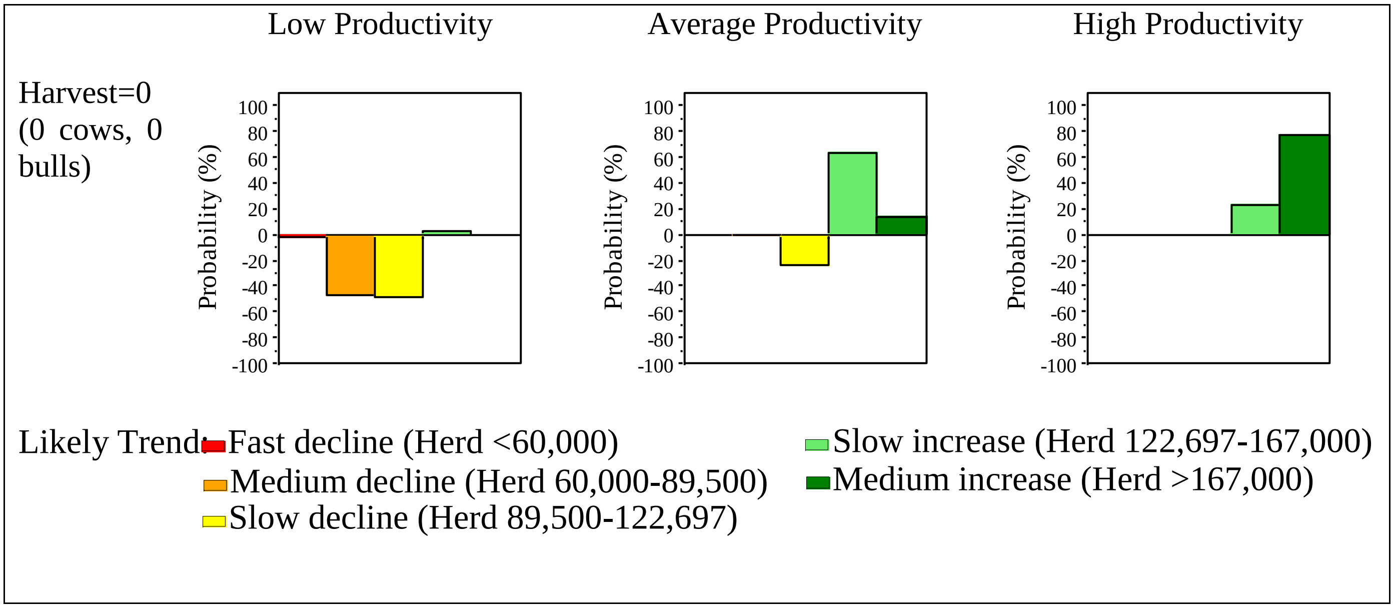

Figure 11: Simulation outcomes under no harvest evaluated at 6 years

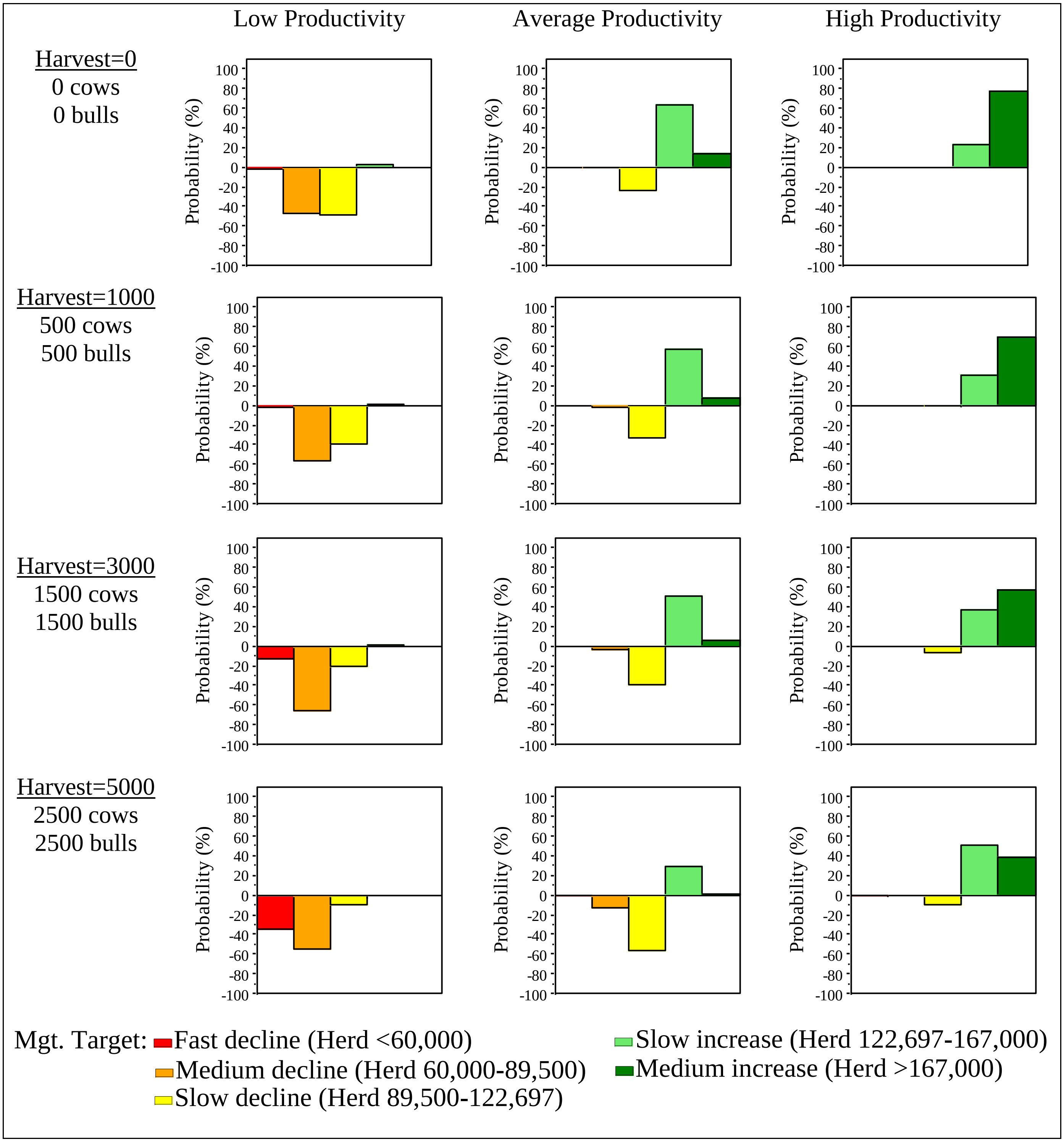

Figure 12: Simulation outcomes under a 50/50 harvest sex ratio evaluated at 6 years

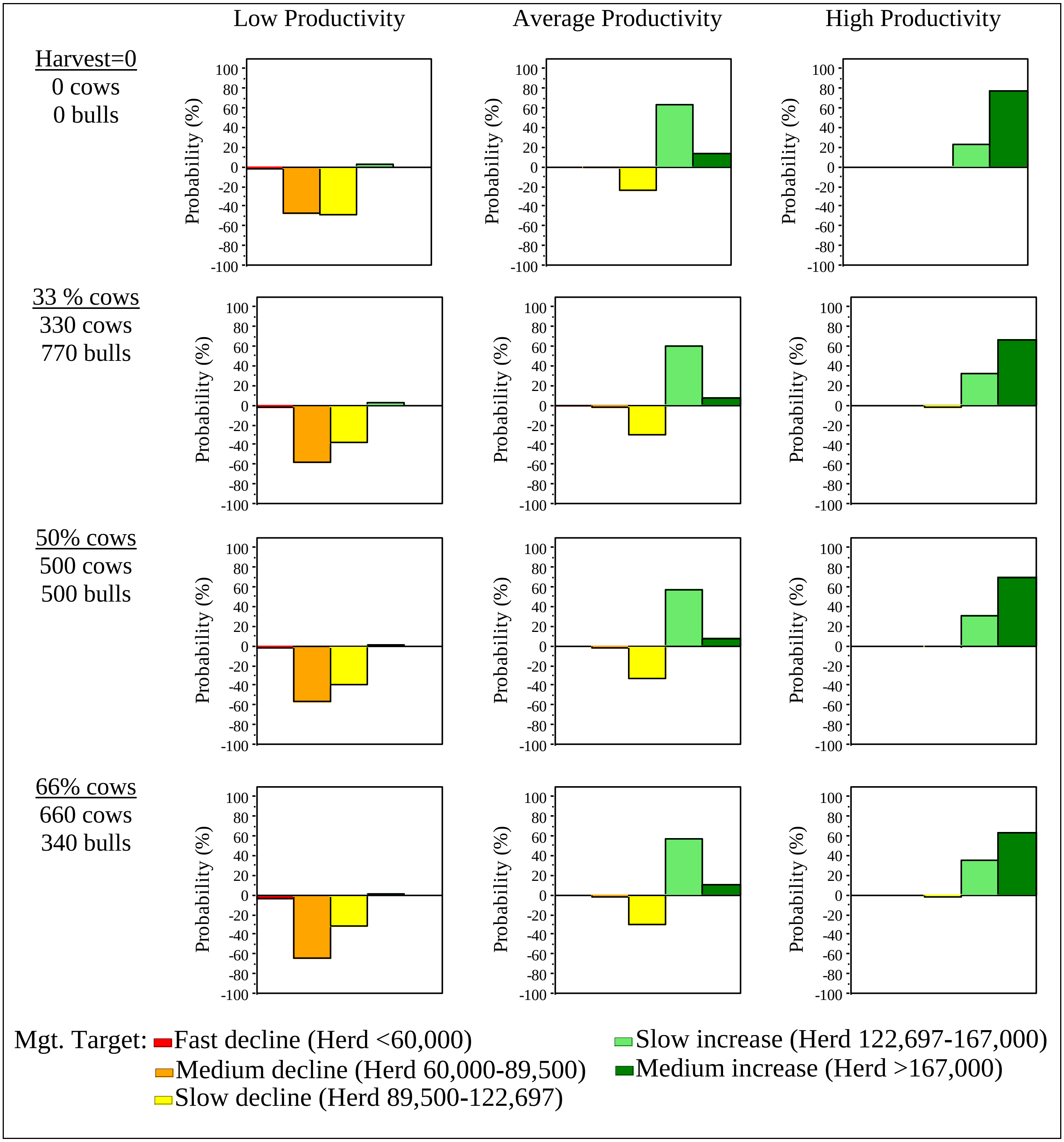

Figure 13: Simulation outcomes under a harvest level of 1000 and various harvest sex ratios evaluated at 6 years

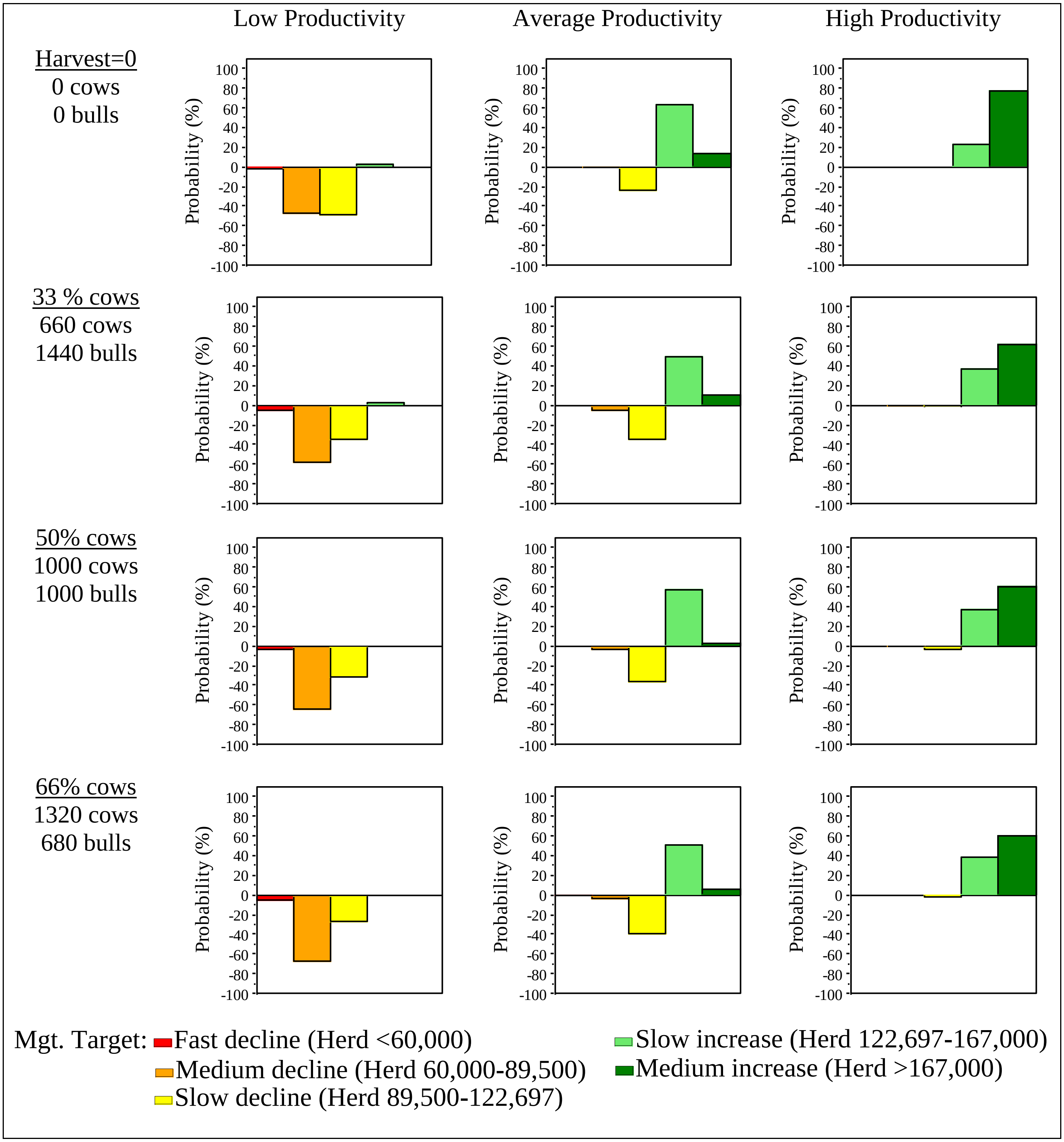

Figure 14: Simulation outcomes under a harvest level of 2000 and various harvest sex ratios evaluated at 6 years

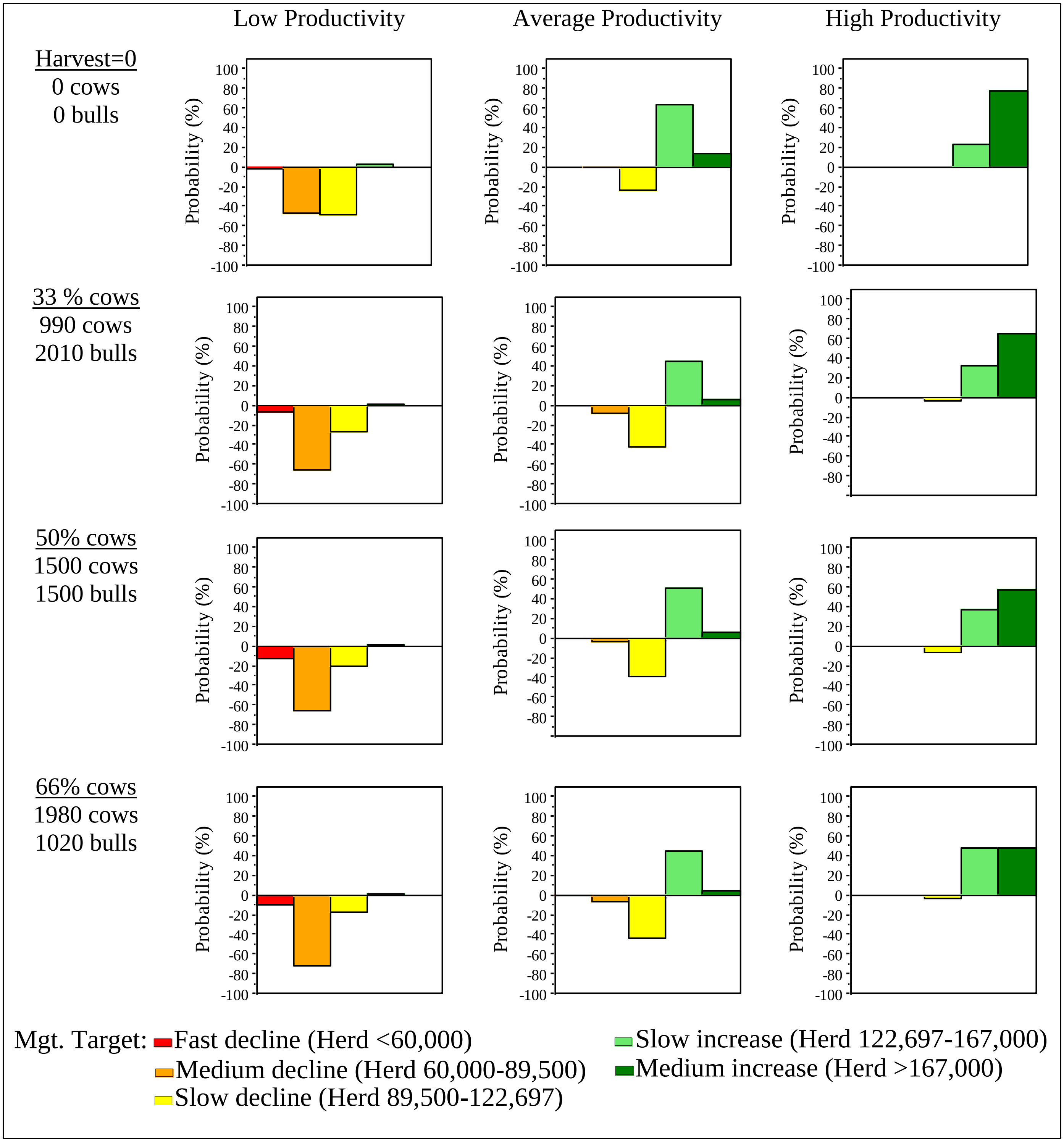

Figure 15: Simulation outcomes under a harvest level of 3000 and various harvest sex ratios evaluated at 6 years

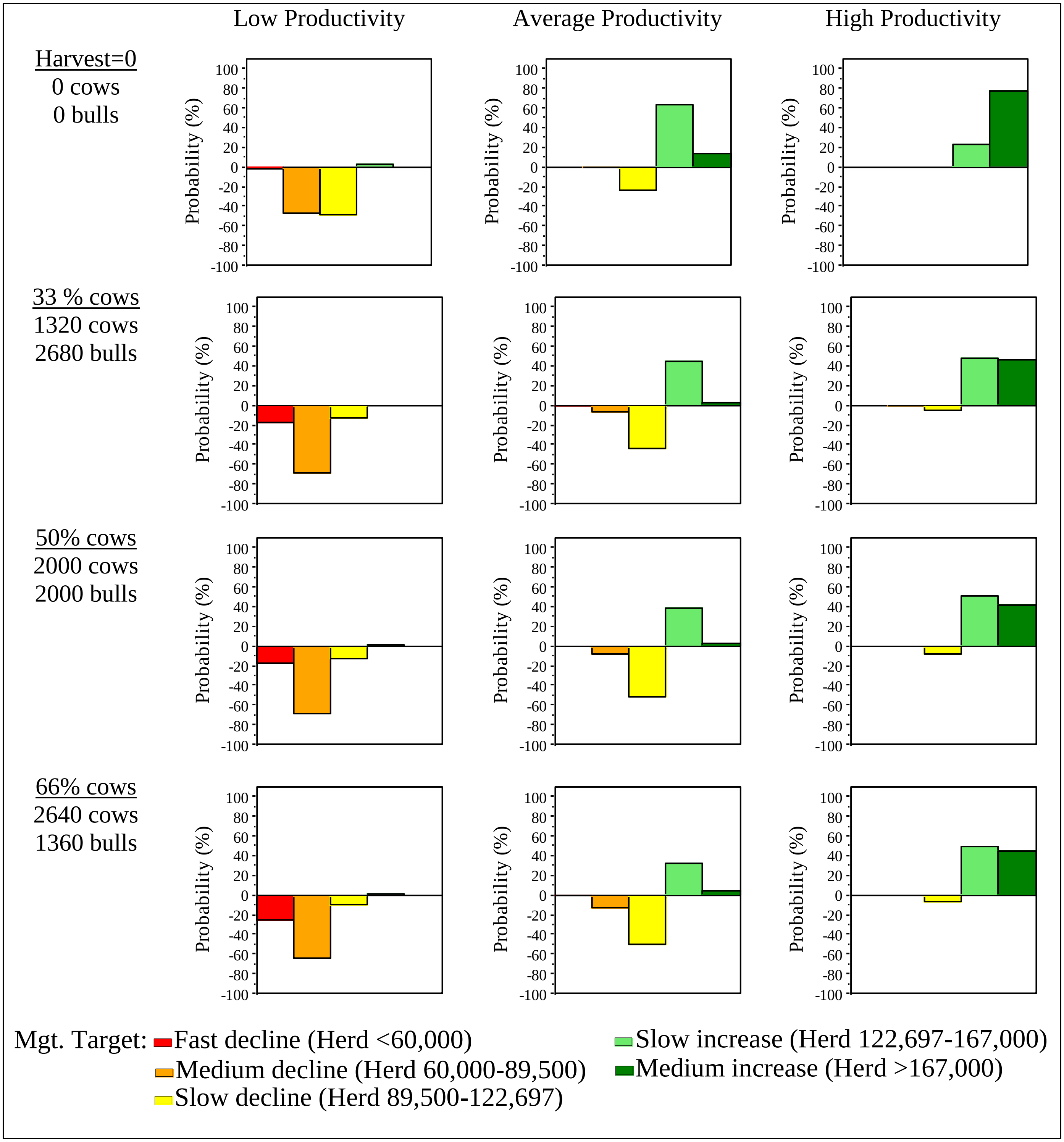

Figure 16: Simulation outcomes under a harvest level of 4000 and various harvest sex ratios evaluated at 6 years

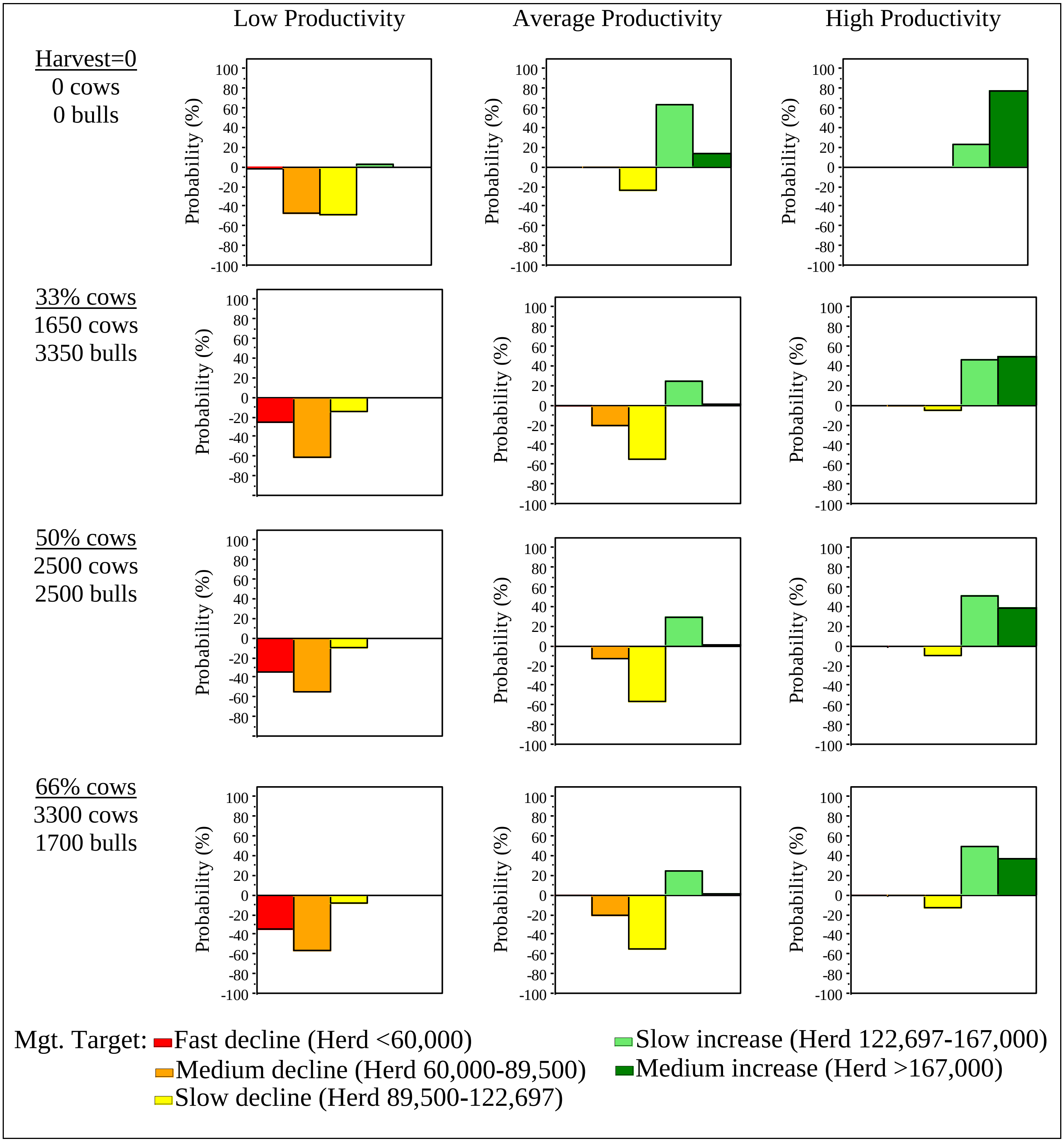

Figure 17: Simulation outcomes under a harvest level of 5000 and various harvest sex ratios evaluated at 6 years

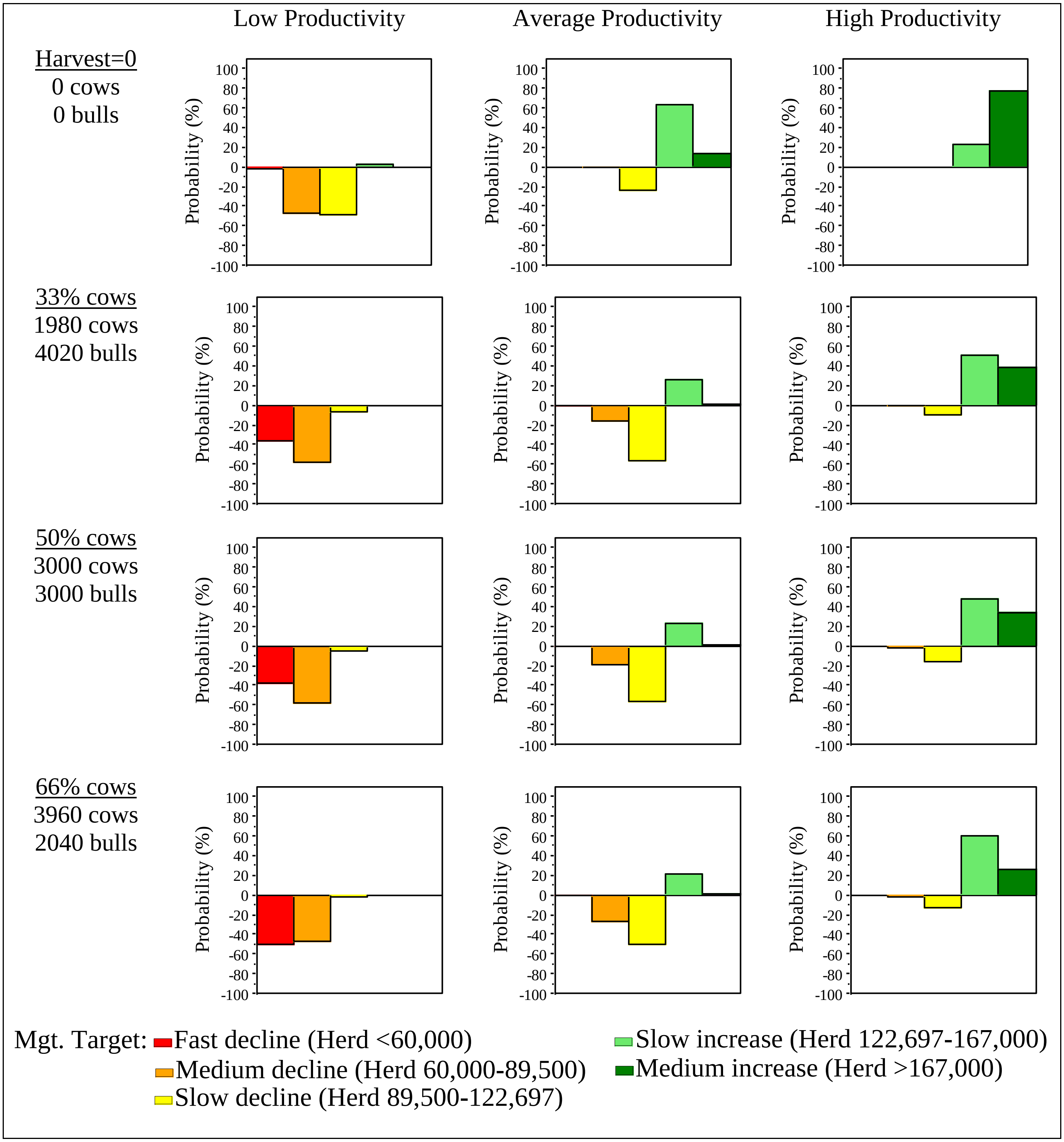

Figure 18: Simulation outcomes under a harvest level of 6000 and various harvest sex ratios evaluated at 6 years