Preliminary Application of Harvest-Based Population Reconstruction to Black-tailed Deer Harvest Data

Progress Report

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This report describes initial efforts to apply harvest-based population reconstruction to black-tailed deer population estimation in western Washington. Following the framework laid out in the proposal (Rice 2011), this has comprised the following elements:

1. Compilation of season and harvest data for black-tailed deer, 2001-2012, for the 63 western Washington GMUs.
2. Development of a population model and likelihood estimators for example GMUs in the framework of ADMB[[1]](#footnote-1).
3. Evaluation of model performance.
4. Plans for further model development.

# Season and Harvest Data

I compiled a database for general and permit hunting seasons for 2001-2012, based on each year’s hunting pamphlet. Where there were multiple GMUs or GMU ranges, I identified each GMU for each season. For Deer Areas, I allocated that season to each GMU (or GMUs) of which the Deer Area was a part. I also retained the designation of whether antlered and/or antlerless deer were legal for each season and the duration of the season for general seasons and the number of permits for permit seasons.

For estimating general season harvest and its standard error, I used the same procedure as is employed for departmental estimates, except I used only westside data. For geographical units (GMU, PMU, Region) with < 5 kills in the phone survey sample, I pooled responses to the broader scale, and then partitioned the pooled estimate according to the total number of reported kills (mandatory report and phone survey) according to the formulas in Rice (2002[[2]](#footnote-2)). In cases where there were no phone survey reports at the westside level (and consequently no estimate from the phone survey or its variance), but there were mandatory reported kills, I extrapolated estimates based on the linear relationship between mandatory reported kills and total estimate for the rest of the cases. The standard errors were estimated similarly. I estimated effort (hunting days) similarly, except pooling was used for geographic units with <10 respondents.

The year 2004 required special treatment because no phone survey was conducted that year. To obtain reasonable harvest and effort estimates, I examined the relationship between mandatory reports of harvest and effort for all other years. This showed that estimated harvest was efficiently estimated by a linear relationship with mandatory reported harvest and the standard error by a linear relationship to the square root of estimated harvest. For effort, the most efficient estimates were partitioned by weapon (Archery, Modern Firearm, and Muzzleloader). I then used the coefficients in these relationships to derive estimated harvest and effort and their standard errors for 2004. Thus, the estimates for 2004 are imputations based on the other years and may be considered an approximation of the result that would have been obtained had a phone survey been conducted in 2004.

For each GMU, Year, Weapon, and Sex, I then estimated the kills per day and estimated its standard error by bootstrap. Records for which there was a season, but with zero harvest and zero effort were considered to have zero kills per day. Thus, for each GMU, Weapon, and Year, the data record showed whether or not there was a season for antlered deer and/or antlerless deer, the estimated hunting effort in days, the estimated harvest for antlered and antlerless deer, and the kills per day for antlered and antlerless deer and their standard errors.

For permit hunts, I totaled the number of permits and harvest for hunt choices in the same GMU, Weapon, and Legal Deer. To obtain an estimate of permits available for hunts with multiple weapons allowed and/or which covered multiple GMUs, I partitioned the total number of permits to each weapon-GMU proportional to the kill reported for each weapon-GMU in each year and GMU. For instance, in 2004, Hunt Choice 1275 (South Soundb) was open to all 3 weapons in 3 GMUs. Thus, the total of 125 permits was partitioned proportional to each Weapon-GMU combination’s share of the reported permit harvest.

I then combined hunts with similar clientele into 10 classes (e.g., 2nd Tag, 65 or Older, Muzzleloader), and summed the number of permits and harvest for each GMU, Year, and Weapon for each class. Lastly, I combined those classes which had <25 permits available in 2001-2012 into a minor class for each GMU. Thus, for the 49 GMUs with permits, each had a variable number of records stating the class of permit and for each year, whether or not permits were available, the number of permits, and the permit harvest for male and female deer.

For each GMU, general and permit season and harvest information was combined into one file suitable for input into ADMB (Appendix A).

# Population Model

For this assessment, I used a simple population model with 4 classes, juveniles and adults for males and females. The annual cycle was between post-hunting seasons. Juveniles of each sex were recruited into the population as a rate per adult female (post-season fawns per female for each sex of fawn). After experiencing annual mortality, juveniles advanced to adults for each sex. Adults for each sex consisted of recruited juveniles and adults from the previous year minus natural mortality (at a given rate) and hunting mortality (number of animals harvested). For adult classes, model estimated general season harvest was calculated as kills per day = vulnerability to harvest \* population size, where vulnerability was the probability of an animal being harvested, would be expected to be a small number and was assumed be constant across years. It is common to use an exponential function to relate harvest probability and effort, but I saw little evidence of a non-linear relationship between effort and harvest in the black-tailed deer harvest data, so I used a linear function.

For permit seasons, effort data are not available. Hence the probability of harvest is considered a function of vulnerability and the number of permits available. Because typically general season harvest is >99% of the antlered harvest and >84% of the antlerless harvest, permit harvest probabilities are not currently incorporated in the model, although the reported permit harvest is included in the total harvest as a mortality factor for each adult class.

Thus, parameters in the model were: initial (Year 1) population sizes for all classes, the recruitment rate for juveniles of both sexes, the natural survival rates for all classes, and the vulnerability to harvest for both adult classes (if both had general and/or permit seasons) for each weapon.

# Likelihoods

Kill per day was the common currency between the harvest data and the population model. Because it was a multiplicative variable, a log-normal likelihood was used, namely:

A constant management regime is one of the assumptions of this approach to population reconstruction, yet season specifications change over time. The *I* index is used above to account for these changes, so that in years that there was no season (*I*i=0), the likelihood will equal 1 and its log will equal 0. Six likelihoods of this form were used, 1 for each sex-weapon combination for general seasons.

When permit harvest is incorporated, it will have a binomial likelihood for each permit class.

The total likelihood for each model is then calculated as the product of the component likelihoods (or the sum of their negative logs, since this is what is actually minimized by ADMB).

# Vulnerability

To minimize the number of parameters which need to be optimized, it is desirable to use one parameter if it is defensible to do so. Vulnerability is a case in point. Vulnerability to harvest can be affected by regulations, by hunter behavior, or by deer behavior. Regulations and/or hunter choice determine which weapon is used for hunting, and because of the difference in efficiency between modern firearm, muzzleloader and archery equipment, it would be expected that vulnerability (per day of hunting) would be different among weapons. Regulations determine which classes of deer may be harvested, so for buck only hunts, antlerless deer vulnerability would be zero, while antlered deer vulnerability would be some value >0. For some hunts, any deer is legal, so whether vulnerability between antlered and antlerless deer may be the same, assuming that hunters are not selective and that deer of each sex are equally available (bucks may be more secretive). In some cases, for a given GMU and weapon combination, the deer that were legal for harvest changed through season. For example, in 2007 in GMU 651, muzzleloader hunters could hunt for any buck from late November to early December, and hunt for any deer from early December to mid-December. Conceivably, harvest could be apportioned between these two hunts, but effort is reported for the entire season. So, antlerless deer are vulnerable for only a part of the season, whereas, antlered deer a vulnerable during all of it, and their vulnerabilities should differ. (We would also expect that the relationship between kills per day and population size would be relatively poor for antlerless deer, because the effort measure is for both hunts.)

# Optimization

Harvest data alone are not sufficient for estimating these parameters, but must be combined with auxiliary data. In this case, the auxiliary data is hunter effort. Harvest data does not contain information about juveniles, so these classes cannot be optimized without further information. (Recruitment into adult classes could be the result of large populations with low survival or the inverse.) Consequently, I fixed these parameters at reasonable values which were not allowed to change during optimization. The objective was to determine if the populations of the adult classes could be optimized using harvest and hunter effort data. The parameters in the model are described in Table 1 (values in the model that are parameters start with ‘P’).

|  |
| --- |
| Table 1. Parameters in the optimization. |
| Parameter | Description | Role |
| PHarvGenArGenFmaleVuln | Female vulnerability to harvest during the general archery season, constant among years | Optimized |
| PHarvGenArGenMaleVuln | Male vulnerability to harvest during the general archery season, constant among years | Optimized |
| PHarvGenMfGenFmaleVuln | Female vulnerability to harvest during the general modern firearm season, constant among years | Optimized |
| PHarvGenMfGenMaleVuln | Male vulnerability to harvest during the general modern firearm season, constant among years | Optimized |
| PHarvGenMzGenFmaleVuln | Female vulnerability to harvest during the general muzzleloader season, constant among years | Optimized |
| PHarvGenMzGenMaleVuln | Male vulnerability to harvest during the general muzzleloader season, constant among years | Optimized |
| PFPSFpD | Female preseason fawns per doe (recruitment) | Fixed |
| PMPSFpD | Male preseason fawns per doe (recruitment) | Fixed |
| PJuvFNatSurv | Juvenile female natural survival | Fixed |
| PJuvMNatSurv | Juvenile male natural survival | Fixed |
| PDoeNatSurv | Adult female natural survival | Optimized |
| PBuckNatSurv | Adult male natural survival | Optimized |
| PJuvFYr1 | Juvenile females Year 1 | Optimized |
| PJuvMYr1 | Juvenile males Year 1 | Optimized |
| PDoeYr1 | Adult females Year 1 | Optimized |
| PBuckYr1 | Adult males Year 1 | Optimized |

# GMU Selection

The level of black-tailed deer harvest has varied a great deal among the 63 GMUs in western Washington (Figure 1). I made a subjective assessment that total harvest, 2001-2012 of <50 would be insufficient for optimization. Hence, there were 3 GMUs with <50 antlerless and <50 antlered deer harvested, 14 GMUs with <50 antlerless and >50 antlered deer harvested, and 46 GMUs with >50 antlerless and >50 antlered deer harvested. I selected 2 GMUs, 564 (Battle Ground) and 651 (Satsop) for initial trials, because these had relatively high harvest totals for both antlered and antlerless deer (Figure 1).



Figure 1. Total antlered and antlerless harvest by GMU, 2001-2012. Red circles=harvest <50 for both antlered and antlerless harvest. Green cross=harvest <50 for antlerless harvest and >50 for antlered harvest. Blue diamond=harvest >50 for both antlered and antlerless harvest. Solid blue diamond=selected GMUs.

GMU 564 had archery, modern firearm, and muzzleloader seasons for antlered and antlerless deer in all years 2001-2012. In GMU 651, there were archery seasons for antlered and antlerless deer in all years, antlered only seasons for modern firearm in all years, and antlered only seasons for muzzleloader hunting in 2001, 2002, 2011, and 2012, with antlered and antlerless hunting 2003-2010.

In both GMUs, if modern firearm hunting was permitted, it accounted for most of the harvest (Figure 2). In GMU 651, in years when antlerless hunting was permitted with muzzleloaders, most of the harvest was by muzzleloader. Modern firearm hunting effort was several-fold higher than archery or muzzleloader hunter effort in both GMUs (Figure 3). Generally speaking, kills per day for antlered deer was of a similar magnitude for archery hunting in GMU 564, modern firearm and muzzleloader hunters in both GMUs, but was lower for archery and muzzleloader hunters in GMU 651 (Figure 4). Antlered kills per day was similar to the former for archery hunters in GMU 564 and muzzleloader hunters in both GMUs, but was lower for archery hunters in GMU 651 and modern firearm hunters in GMU 564. The standard errors of the estimated kills per day for modern firearm hunting were typically a small proportion of the estimate (Figure 4), but for other weapons, standard errors often were as large as the estimate, or even several times the estimate.







Figure 2. Estimated antlered and antlerless harvest for GMUs 564 and 651, 2001-2012 by weapon.

Judging from the kills per day across years (Figure 4), I judged that in GMU 564 there was little evidence of differential vulnerability between antlered and antlerless deer for archery and muzzleloader hunting, so I used 1 vulnerability parameter for both sexes. However, kill per day was consistently higher for antlered deer than for antlerless deer for modern firearm hunting, so these sexes had separate vulnerability parameters for modern firearm. In GMU 651, kill per day was comparable between the sexes for archery hunting, so 1 parameter should suffice. There was no antlerless modern firearm season, so only antlered vulnerability entered the calculations, and for muzzleloader, there was an obvious difference between kill per day, so 1 parameter for each sex was called for.



Figure 3. Estimated hunter effort for GMUs 564 and 651, 2001-2012 by weapon.

# ADMB Implementation





Figure 4. Estimated antlered and antlerless kills per day for GMUs 564 and 651, 2001-2012 by weapon. Error bars=standard error.

ADMB scripts are written in code that follows many of the conventions of C++. To execute the script, ADMB converts it to a C++ program which is then compiled and linked with the AUTODIF (automatic differentiation) library. The complied executable file is then run, which reads the data from a text file and produces various output files including a log file and a report file. Each modification to the script requires that this sequence be repeated. To facilitate this process I used PBSadmb[[3]](#footnote-3), which is an R package which provides an interface to perform these operations.

The ADMB script for GMU 651 is given in Appendix B. The DATA\_SECTION reads the data file into named variables. The PARAMETER\_SECTION declares parameters and model variables. I declared parameters as bounded (in parenthesis) to keep them within biologically reasonable limits. A value of -1 in the last position in the parenthesis was used to remove selected parameters from the optimization. In the PRELIMINARY\_CALCS\_SECTION, I specified initial values for the parameters (and fixed values for parameters not currently in the optimization, e.g., juvenile survival) and calculated total harvest for each sex.

The PROCEDURE\_SECTION contains the population model and calculates the likelihoods. In the population model, I used the posfun function to penalize optimization cases where the population of adults was less than the harvest that year for each sex. The REPORT\_SECTION writes the results of the optimization to a report file.

# Optimization Results and Variations

For GMU 564, the model optimization produced extremely high population levels with a population many billions adult females adult males. This was, of course, accompanied by very low vulnerability (e.g., 5.0x10-015 for females and 1.5x10-014 for males). These optimizations consistently produced the message 'Function minimizer not making progress'. Attempts to eliminate this by fixing female natural mortality and male natural mortality, changing starting values, and by adjusting the parameter scale factors so that gradients were of comparable magnitude were not successful.

Optimizations for GMU 651 produced similar results, extremely high populations with very low vulnerability.

To investigate this further, I developed a model of females only (juvenile and adult) and used the modern firearm antlerless harvest for GMU 564. This model behaved similarly, with the population optimized with millions of deer and low vulnerability. However, I noticed when adjusting the parameter bounds for vulnerability, that the likelihood values were not very different at lower values of vulnerability. So, I experimented with setting the vulnerability parameter at specific values. Vulnerability >2x10-5 triggered the population < harvest penalty. The negative log-likelihood (NLL) declined steeply among higher values of vulnerability, but changed little among lower values (Figure 5). However, the lowest vulnerability does have slightly lower NLL than those above it. (The difference between 1x10-11 1x10-10 is about a thousandth of a percent). So unconstrained, the optimizer finds very low vulnerability values. It appears that the optimization is suitable for determining the upper limits to vulnerability, but not the lower limits. Based on Figure 5, if we were to visually select a value where the curve levels off as 2x10-6, this would yield a 2012 population of 4,663 adult females in GMU 564, or 3.4 adult females per km2. This seems a reasonable estimate, but it is important to note that the population size will be inversely proportional to the vulnerability. We might have as easily picked 1x10-6 as the leveling off point, in which case the population estimate would be about double what is was for 2x10-6. (Forcing vulnerabilities higher for the complete model (3 weapons and 2 sexes) revealed comparable behavior, i.e., the NLL dropped rapidly a higher values and very slowly at lower values).

# Prognosis

Figure. 6. Negative log-likelihood of optimization model for adult females in GMU 564 with vulnerability (Vuln) fixed at various values.

The models discussed above depend on the assumption that kills per day is proportional to population size. However, with fixed values for recruitment and juvenile mortality and constant adult natural survival, the basic trend of the population is already determined. Thus, this optimization should find the overall population sized consistent with the overall kills per day, given that the precision of the estimated kills per day varies among years (and weapons). Also, unlike survey data (which for black-tailed deer can only be expected to reflect relative abundance), harvest also removes animals from the population. Given that the majority of the harvest and higher precision for kills per day was for modern firearm hunting, we would expect modern firearm data to be the primary determinant in optimization. Whether or not these data can suffice to determine the vulnerability and hence population size, depends on the validity of the relationship between population size and kills per day, the variability in the amount of effort across years, and the precision of the estimates of kills per day. For modern firearm hunting, effort varied 2-3 fold (maximum/minimum) across years. Yet at least for these 2 GMUs, only the upper bounds of vulnerability were effectively determined.

I conclude that additional auxiliary data is needed to optimize our models of harvest-based population reconstruction even for estimating harvested classes of deer. As noted, aerial or spotlight surveys can only provide measures of relative abundance among years or classes and therefore, cannot improve estimation of vulnerability or the magnitude of the population. An independent assessment of population size is not feasible for black-tailed deer, so an independent assessment of vulnerability is needed. This could be obtained with radio-tagged individuals. However, to obtain data on risk of harvest for each GMU for each sex for each year for each weapon would be so impractical as to be ludicrous. Consequently some sort of combined estimate would need to be applied. This might be accomplished by integrating risk among weapons, and careful consideration of pooling among GMUs. Nevertheless, this could not be accomplished without considerable effort and expense. Given the small differences in likelihood in the lower region of vulnerability values, even an imprecise estimate of vulnerability (with low sample size) may serve to stabilize the optimizations. However, because of the sensitivity of the population estimate to the vulnerability value, bias, especially negative bias, in the independent vulnerability estimate would detrimentally affect the population estimate.

The need to estimate vulnerability is uncomfortably SAK-like, in that a parameter that is difficult to measure is of critical importance in deriving the population estimate. However, by modeling the populations over a number of years instead of within one year, a more stable estimate can be anticipated. In fact, the reverse is probably the case. Because of the need to keep certain parameters constant across years, these models will probably fluctuate less than the actual population.

At present, I have only attempted to estimate the adult classes in these models. Future development will include additional likelihoods relating composition data from surveys and incidental observations, as well as data from tagged animals where suitable, to provide population estimates for the juvenile classes as well. In addition, recent work indicates that to obtain proper precision estimates, a 2-stage random effects modeling procedure should be used (Gast et al. 2013), and this should be incorporated in future modeling.

# Addendum Nov 2013

## Model form

Many harvest-based models use modeled harvest as the foundation for the likelihood. I did not do this because both effort and harvest are estimated for each GMU. Consequently, I combined them (and their standard errors) into kills per day. Possibly, including harvest and effort in a mixed effects model would be another way to account for this.

Much of the literature on the application of maximum likelihood model fitting in wildlife incorporates age at harvest information. Such information is available after a fashion for buck harvest in Washington as hunters report the number of antler points in the bucks they harvest. However, there is only a loose relationship between antler points and age, so either the transition probabilities between antler point classes must be determined for a stage-based model, or antler point classes must be proportionally assigned to age classes. The limited data there is on this suggests that these proportions vary geographically, so that using antler point classes would necessitate fitting a number of additional parameters in the model.

Dental sections from teeth submitted by hunters are a potential source of age at harvest information. In Washington, teeth are not currently submitted by deer hunters, but a voluntary program could conceivably be initiated. However, it is thought that voluntary submissions are likely to be biased for bucks, but may be representative for does.

It is unclear to me if or how including age at harvest would improve the optimization. It would appear that the adult age classes are already contained in the single classes for each sex so that age information could only provide more detail within the adults. This would not be unwelcome, but would not seem to address the main problem encountered here.

## Additional information

I suggested above that field measures of vulnerability could be used as auxiliary data to provide a joint likelihood to allow the model to optimize at a suitable state. However, this may be excessively costly. An alternative might be to provide prior distributions for population and/or vulnerability. The analysis could then be conducted in a Bayesian framework, or these distributions used in penalty functions in a frequentist setting. We might use reports from the literature to determine a suitable vulnerability coefficient or out from SAK analysis for an estimate of population size. The expectation would be that these priors or penalty functions would prevent the optimization from ‘sliding down’ the nearly level left tail of the current likelihood shape (Figure 6).

# Literature Cited

Gast, C., J.R. Skalski, and D.E. Beyer. 2013. Evaluation of fixed- and random-effects models and multistage estimation procedures in statistical population reconstruction. The Journal of Wildlife Management 77(6):1258–1270.

Rice, C.G. 2011. Harvest-based Population Estimation for Black-tailed Deer. Unpublished proposal. January 2011. Washington Department of Fish and Wildlife.

# Appendix A.

Example data input file for GMU 651. # denotes comment lines.

#GMU 651

#General Seasons

#WeaponOrClass Archery

#Had Season

1 1 1 1 1 1 1 1 1 1 1 1

#Antlered Season

1 1 1 1 1 1 1 1 1 1 1 1

#Antlerless Season

1 1 1 1 1 1 1 1 1 1 1 1

#Effort

500 577 620 581 801 660 956 1351 702 1325 741 523

#K Antlered

5.2 5.6 8.5 15.9 10.2 8.9 8.7 2.6 10.7 9 5.6 3

#K Antlerless

5.1 6.6 2.6 12 8.8 15.2 6.7 3.2 7.5 15.7 8.1 15.9

#KpD Antlered

0.0105 0.0098 0.0136 0.0274 0.0127 0.0134 0.0091 0.0019 0.0152 0.0068 0.0075 0.0058

#SE KpD Antlered

0.31028 0.21173 0.01928 0.03064 0.006 0.01238 0.14693 0.00411 0.04796 0.00455 0.0128 0.00944

#KpD Antlerless

0.0101 0.0115 0.0043 0.0207 0.011 0.023 0.007 0.0024 0.0106 0.0119 0.0109 0.0305

#SE KpD Antlerless

0.1994 0.17535 0.0073 0.03072 0.00495 0.01634 0.13416 0.00665 0.01545 0.00721 0.01934 0.02628

#WeaponOrClass Modern Firearm

#Had Season

1 1 1 1 1 1 1 1 1 1 1 1

#Antlered Season

1 1 1 1 1 1 1 1 1 1 1 1

#Antlerless Season

0 0 0 0 0 0 0 0 0 0 0 0

#Effort

12856 12626 12724 11896 10997 10758 9568 11384 10334 8100 8319 7474

#K Antlered

559.2 452 555 779.6 349.2 282.3 285.7 380.5 274.6 292 241.4 354.2

#K Antlerless

0 0 0 0 0 0 0 0 0 0 0 0

#KpD Antlered

0.0435 0.0358 0.0436 0.0655 0.0318 0.0262 0.0299 0.0334 0.0266 0.0361 0.029 0.0474

#SE KpD Antlered

0.00534 0.00632 0.00348 0.00638 0.00215 0.00283 0.00344 0.00614 0.0037 0.00319 0.00324 0.00499

#KpD Antlerless

0 0 0 0 0 0 0 0 0 0 0 0

#SE KpD Antlerless

0 0 0 0 0 0 0 0 0 0 0 0

#WeaponOrClass Muzzleloader

#Had Season

1 1 1 1 1 1 1 1 1 1 1 1

#Antlered Season

1 1 1 1 1 1 1 1 1 1 1 1

#Antlerless Season

0 0 1 1 1 1 1 1 1 1 0 0

#Effort

974 1232 2570 2640 2297 2251 1749 2026 1848 1730 773 786

#K Antlered

12.2 10.3 55.7 50.9 27.8 30.9 17.3 15.4 24.9 32.5 6 4.6

#K Antlerless

0 0 129.1 156 73 86.9 60.3 43.2 84.9 73 0 0

#KpD Antlered

0.0125 0.0084 0.0217 0.0193 0.0121 0.0137 0.0099 0.0076 0.0135 0.0188 0.0078 0.0059

#SE KpD Antlered

0.01135 0.01211 0.00658 0.00637 0.00305 0.00378 0.00321 0.43999 0.00604 0.00475 0.00118 0.00445

#KpD Antlerless

0 0 0.0502 0.0591 0.0318 0.0386 0.0345 0.0213 0.0459 0.0422 0 0

#SE KpD Antlerless

0 0 0.00736 0.01324 0.00456 0.00801 0.01215 1.96157 0.01421 0.00398 0 0

#Permit Seasons

#WeaponOrClass Minor

#HadPermits

1 1 0 0 0 0 0 0 0 0 0 0

#Permits

52 51 0 0 0 0 0 0 0 0 0 0

#MaleKill

2 2 0 0 0 0 0 0 0 0 0 0

#FemaleKill

9 5 0 0 0 0 0 0 0 0 0 0

#WeaponOrClass Modern Firearm-Modern Firearm

#HadPermits

1 1 1 1 1 1 1 1 1 1 1 1

#Permits

158 159 10 10 10 20 10 10 10 10 10 10

#MaleKill

20 26 5 2 5 5 4 6 5 2 9 4

#FemaleKill

44 26 0 0 0 4 0 0 0 0 0 0

#WeaponOrClass Modern Firearm-Youth

#HadPermits

1 1 1 1 1 0 1 1 1 1 1 1

#Permits

10 10 10 10 10 0 10 10 10 10 10 10

#MaleKill

4 3 2 2 0 0 3 1 0 4 0 0

#FemaleKill

0 3 3 2 4 0 3 2 4 0 6 6

#WeaponOrClass Muzzleloader-Antlerless

#HadPermits

0 0 0 0 0 0 0 0 0 0 1 1

#Permits

0 0 0 0 0 0 0 0 0 0 100 100

#MaleKill

0 0 0 0 0 0 0 0 0 0 0 0

#FemaleKill

0 0 0 0 0 0 0 0 0 0 10 31

# Appendix B.

ADMB Script for GMU 651. // denotes comment lines.

//4 classes, juv & adult of male and female

//fawns become juveniles at hunting season

//fawns & juveniles without harvest--built on assumed parameters

//harvest data for general and permit seasons

//no surveys

//constant survival for adults

//constant vulnerability for each harvest

//Variables that are data begin with 'Dat'

//Variables that are calculated in the model begin with 'M'

//Model parameters begin with 'P'

//Harv=Harvest, Gen=General seasons, Ar=Archery, Mf=Modern firearm, Mz=Muzzleloader

//Male=Male, Fmale=Female

//Seas=Season, Effort=hunter Effort (days), KpD=Kills per Day, KpDSE=Standard Effor of Kills per Day

//further definitions below

DATA\_SECTION

 //read data

 //General Archery

 init\_vector DatHarvGenArGenSeas(1,12)

 init\_vector DatHarvGenArMaleSeas(1,12)

 init\_vector DatHarvGenArFmaleSeas(1,12)

 init\_vector DatHarvGenArEffort(1,12)

 init\_vector DatHarvGenArMaleHarv(1,12)

 init\_vector DatHarvGenArFmaleHarv(1,12)

 init\_vector DatHarvGenArMaleKpD(1,12)

 init\_vector DatHarvGenArMaleKpDSE(1,12)

 init\_vector DatHarvGenArFmaleKpD(1,12)

 init\_vector DatHarvGenArFmaleKpDSE(1,12)

 //General Modern firearm

 init\_vector DatHarvGenMfGenSeas(1,12)

 init\_vector DatHarvGenMfMaleSeas(1,12)

 init\_vector DatHarvGenMfFmaleSeas(1,12)

 init\_vector DatHarvGenMfEffort(1,12)

 init\_vector DatHarvGenMfMaleHarv(1,12)

 init\_vector DatHarvGenMfFmaleHarv(1,12)

 init\_vector DatHarvGenMfMaleKpD(1,12)

 init\_vector DatHarvGenMfMaleKpDSE(1,12)

 init\_vector DatHarvGenMfFmaleKpD(1,12)

 init\_vector DatHarvGenMfFmaleKpDSE(1,12)

 //General Muzzleloader

 init\_vector DatHarvGenMzGenSeas(1,12)

 init\_vector DatHarvGenMzMaleSeas(1,12)

 init\_vector DatHarvGenMzFmaleSeas(1,12)

 init\_vector DatHarvGenMzEffort(1,12)

 init\_vector DatHarvGenMzMaleHarv(1,12)

 init\_vector DatHarvGenMzFmaleHarv(1,12)

 init\_vector DatHarvGenMzMaleKpD(1,12)

 init\_vector DatHarvGenMzMaleKpDSE(1,12)

 init\_vector DatHarvGenMzFmaleKpD(1,12)

 init\_vector DatHarvGenMzFmaleKpDSE(1,12)

 //Permits Minor

 init\_vector DatHarvPmtMinorHad(1,12)

 init\_vector DatHarvPmtMinorPmts(1,12)

 init\_vector DatHarvPmtMinorMaleHarv(1,12)

 init\_vector DatHarvPmtMinorFmaleHarv(1,12)

 //Permits Modern firearm-Modern firearm

 init\_vector DatHarvPmtMfMfHad(1,12)

 init\_vector DatHarvPmtMfMfPmts(1,12)

 init\_vector DatHarvPmtMfMfMaleHarv(1,12)

 init\_vector DatHarvPmtMfMfFmaleHarv(1,12)

 //Permits Modern firearm-Youth

 init\_vector DatHarvPmtMfYoHad(1,12)

 init\_vector DatHarvPmtMfYoPmts(1,12)

 init\_vector DatHarvPmtMfYoMaleHarv(1,12)

 init\_vector DatHarvPmtMfYoFmaleHarv(1,12)

 //Permits Muzzloader Antlerless

 init\_vector DatHarvPmtMzAlHad(1,12)

 init\_vector DatHarvPmtMzAlPmts(1,12)

 init\_vector DatHarvPmtMzAlMaleHarv(1,12)

 init\_vector DatHarvPmtMzAlFmaleHarv(1,12)

 vector DatMaleTotHarv(1,12);

 vector DatFmaleTotHarv(1,12);

PARAMETER\_SECTION

 init\_bounded\_number PHarvGenArGenVuln(1.0e-018,0.0010,1) //Harvest General Archery Vulnerability for both sexes

 init\_bounded\_number PHarvGenMfGenVuln(1.0e-018,0.0010,1) //Harvest General Modern firearm Vulnerability for both sexes

 init\_bounded\_number PHarvGenMzGenFmaleVuln(1.0e-018,0.0010,2) //Harvest General Muzzleloader Vulnerability for females

 init\_bounded\_number PHarvGenMzGenMaleVuln(1.0e-018,0.0010,2) //Harvest General Muzzleloader Vulnerability for males

 init\_bounded\_vector PFPSFpD(1,12,0.25,0.25,-1) //Female PreSeason Fawns per doe (recruitment)

 init\_bounded\_vector PMPSFpD(1,12,0.20,0.20,-1) //Male PreSeason Fawns per doe (recruitment)

 init\_bounded\_vector PJuvFNatSurv(1,12,0.8,0.8,-1) //Juvenile female natural survival

 init\_bounded\_vector PJuvMNatSurv(1,12,0.75,0.75,-1) //Juvenile male natural survival

 init\_bounded\_number PDoeNatSurv(0.6,0.9) //doe natural survival

 init\_bounded\_number PBuckNatSurv(0.6,0.9) //buck natural survival

 init\_bounded\_number PJuvFYr1(100,1.0e+018) //Juvinile females Year 1

 init\_bounded\_number PJuvMYr1(100,1.0e+018) //Juvenile males Year 1

 init\_bounded\_number PDoeYr1(100,1.0e+018) //Does Year 1

 init\_bounded\_number PBuckYr1(100,1.0e+018) //Bucks Year 1

 vector MJuvFPop(1,12) //Juvenile female population size

 vector MJuvMPop(1,12) //Juvenile male population size

 vector MJuvPop(1,12) //Juvenile population size (males and females)

 vector MDoePop(1,12) //Doe population size

 vector MBuckPop(1,12) //Buck population size

 vector MJDPop(1,12) //Juvenile and doe population size

 vector MPopLTHarvPenYr(1,12) //Population less than harvest posfun penalty by yr

 number MPopLTHarvPenalty //Population less than harvest penalty

 vector MHarvGenArMaleKpD(1,12) //Modelled kill per day for General Archery Males given pop size, vulnerability, and if there was a season

 vector MLHarvGenArMaleKpDp1(1,12) //Log KpD likelihood part 1

 vector MLHarvGenArMaleKpDp2(1,12) //Log KpD likelihood part 2

 vector MLHarvGenArMaleKpDYr(1,12) //Negative log liklihood for KpD, each yr

 number MNLLHarvGenArMaleKpD //Negative log liklihood across years for KpD General Archery Males

 vector MHarvGenArFmaleKpD(1,12) //Modelled kill per day for General Archery Females given pop size, vulnerability, and if there was a season

 vector MLHarvGenArFmaleKpDp1(1,12) //Log KpD likelihood part 1

 vector MLHarvGenArFmaleKpDp2(1,12) //Log KpD likelihood part 2

 vector MLHarvGenArFmaleKpDYr(1,12) //Negative log liklihood for KpD, each yr

 number MNLLHarvGenArFmaleKpD //Negative log liklihood across years for KpD General Archery Females

 vector MHarvGenMfMaleKpD(1,12) //Modelled kill per day for General Modern firearm Males given pop size, vulnerability, and if there was a season

 vector MLHarvGenMfMaleKpDp1(1,12) //Log KpD likelihood part 1

 vector MLHarvGenMfMaleKpDp2(1,12) //Log KpD likelihood part 2

 vector MLHarvGenMfMaleKpDYr(1,12) //Negative log liklihood for KpD, each yr

 number MNLLHarvGenMfMaleKpD //Negative log liklihood across years for KpD General Modern firearm Males

 vector MHarvGenMfFmaleKpD(1,12) //Modelled kill per day for General Modern firearm Females given pop size, vulnerability, and if there was a season

 vector MLHarvGenMfFmaleKpDp1(1,12) //Log KpD likelihood part 1

 vector MLHarvGenMfFmaleKpDp2(1,12) //Log KpD likelihood part 2

 vector MLHarvGenMfFmaleKpDYr(1,12) //Negative log liklihood for KpD, each yr

 number MNLLHarvGenMfFmaleKpD //Negative log liklihood across years for KpD General Modern firearm Females

 vector MHarvGenMzMaleKpD(1,12) //Modelled kill per day for General Muzzloader Males given pop size, vulnerability, and if there was a season

 vector MLHarvGenMzMaleKpDp1(1,12) //Log KpD likelihood part 1

 vector MLHarvGenMzMaleKpDp2(1,12) //Log KpD likelihood part 2

 vector MLHarvGenMzMaleKpDYr(1,12) //Negative log liklihood for KpD, each yr

 number MNLLHarvGenMzMaleKpD //Negative log liklihood across years for KpD General Muzzloader Males

 vector MHarvGenMzFmaleKpD(1,12) //Modelled kill per day for General Muzzloader Females given pop size, vulnerability, and if there was a season

 vector MLHarvGenMzFmaleKpDp1(1,12) //Log KpD likelihood part 1

 vector MLHarvGenMzFmaleKpDp2(1,12) //Log KpD likelihood part 2

 vector MLHarvGenMzFmaleKpDYr(1,12) //Negative log liklihood for KpD, each yr

 number MNLLHarvGenMzFmaleKpD //Negative log liklihood across years for KpD General Muzzloader Females

 number OptCounter //Optimization counter

 objective\_function\_value NLLTot //Minnimize total NLL

PRELIMINARY\_CALCS\_SECTION

 //Initial values

 PHarvGenArGenVuln=1.0e-9;

 PHarvGenMfGenVuln=1.0e-9;

 PHarvGenMzGenFmaleVuln=1.0e-9;

 PHarvGenMzGenMaleVuln=1.0e-9;

 PDoeNatSurv=0.71;

 PBuckNatSurv=0.71;

 PJuvFYr1=5000;

 PJuvMYr1=5000;

 PDoeYr1=5000;

 PBuckYr1=5000;

 DatMaleTotHarv=DatHarvGenArMaleHarv+DatHarvGenMfMaleHarv+DatHarvGenMzMaleHarv+DatHarvPmtMinorMaleHarv+DatHarvPmtMfMfMaleHarv+DatHarvPmtMfYoMaleHarv+DatHarvPmtMzAlMaleHarv;

 DatFmaleTotHarv=DatHarvGenArFmaleHarv+DatHarvGenMfFmaleHarv+DatHarvGenMzFmaleHarv+DatHarvPmtMinorFmaleHarv+DatHarvPmtMfMfFmaleHarv+DatHarvPmtMfYoFmaleHarv+DatHarvPmtMzAlFmaleHarv;

PROCEDURE\_SECTION

 OptCounter=OptCounter+1;

 MPopLTHarvPenYr=(0,0,0,0,0,0,0,0,0,0,0,0);

 //Population model with posfun for Harv

 //Population cannot be less than number harvested

 //Assign initial year values with posfuns

 MJuvFPop[1]=PJuvFYr1;

 MJuvMPop[1]=PJuvMYr1;

 MDoePop[1]=posfun(PDoeYr1, DatFmaleTotHarv[1], MPopLTHarvPenYr[1]);

 MBuckPop[1]=posfun(PBuckYr1, DatMaleTotHarv[1], MPopLTHarvPenYr[1]);

 //for subsequent years

 for (int i=2;i<=12;i++) {

 MJuvFPop[i]=(MDoePop[i-1])\*PDoeNatSurv\*PFPSFpD[i-1];

 MJuvMPop[i]=(MDoePop[i-1])\*PDoeNatSurv\*PMPSFpD[i-1];

 MDoePop[i]=MDoePop[i-1]\*PDoeNatSurv+MJuvFPop[i-1]\*PJuvFNatSurv[i-1]-DatFmaleTotHarv[i];

 MDoePop[i]=posfun(MDoePop[i], DatFmaleTotHarv[i], MPopLTHarvPenYr[i]);

 MBuckPop[i]=MBuckPop[i-1]\*PBuckNatSurv+MJuvMPop[i-1]\*PJuvMNatSurv[i-1]-DatMaleTotHarv[i];

 MBuckPop[i]=posfun(MBuckPop[i], DatMaleTotHarv[i], MPopLTHarvPenYr[i]);

 } // end for (int i=2;i<=12;i++)

 //add tuning scalar - 0.01

 MPopLTHarvPenalty = 0.01\*sum(MPopLTHarvPenYr);

 //Calculate likelihoods

 //Modelled KillperDay is Pop\*Season or not\*Vuln

 //Couldn't get the pow() function to work with parameters, so added 10^-100 to 0 SE^2s to avoid div by zero

 //Also added 10^-100 to KpDs to avoid log(KpD) errors

 //for General Archery Male

 MHarvGenArMaleKpD=elem\_prod(MBuckPop,DatHarvGenArMaleSeas)\*PHarvGenArGenVuln;

 MLHarvGenArMaleKpDp1=log(pow(1/(sqrt(2\*M\_PI)\*elem\_prod(DatHarvGenArMaleKpDSE,DatHarvGenArMaleKpD)), DatHarvGenArMaleSeas));

 MLHarvGenArMaleKpDp2=elem\_prod(elem\_div(-square(log(DatHarvGenArMaleKpD+pow(10,-100))-log(MHarvGenArMaleKpD+pow(10,-100))),2\*square(DatHarvGenArMaleKpDSE)+pow(10,-100)), DatHarvGenArMaleSeas);

 MLHarvGenArMaleKpDYr=-(MLHarvGenArMaleKpDp1+MLHarvGenArMaleKpDp2);

 MNLLHarvGenArMaleKpD=sum(MLHarvGenArMaleKpDYr);

 //for General Archery Female

 MHarvGenArFmaleKpD=elem\_prod(MDoePop,DatHarvGenArFmaleSeas)\*PHarvGenArGenVuln;

 MLHarvGenArFmaleKpDp1=log(pow(1/(sqrt(2\*M\_PI)\*elem\_prod(DatHarvGenArFmaleKpDSE,DatHarvGenArFmaleKpD)), DatHarvGenArFmaleSeas));

 MLHarvGenArFmaleKpDp2=elem\_prod(elem\_div(-square(log(DatHarvGenArFmaleKpD+pow(10,-100))-log(MHarvGenArFmaleKpD+pow(10,-100))),2\*square(DatHarvGenArFmaleKpDSE)+pow(10,-100)), DatHarvGenArFmaleSeas);

 MLHarvGenArFmaleKpDYr=-(MLHarvGenArFmaleKpDp1+MLHarvGenArFmaleKpDp2);

 MNLLHarvGenArFmaleKpD=sum(MLHarvGenArFmaleKpDYr);

 //for General Modern firearm Male

 MHarvGenMfMaleKpD=elem\_prod(MBuckPop,DatHarvGenMfMaleSeas)\*PHarvGenMfGenVuln;

 MLHarvGenMfMaleKpDp1=log(pow(1/(sqrt(2\*M\_PI)\*elem\_prod(DatHarvGenMfMaleKpDSE,DatHarvGenMfMaleKpD)), DatHarvGenMfMaleSeas));

 MLHarvGenMfMaleKpDp2=elem\_prod(elem\_div(-square(log(DatHarvGenMfMaleKpD+pow(10,-100))-log(MHarvGenMfMaleKpD+pow(10,-100))),2\*square(DatHarvGenMfMaleKpDSE)+pow(10,-100)), DatHarvGenMfMaleSeas);

 MLHarvGenMfMaleKpDYr=-(MLHarvGenMfMaleKpDp1+MLHarvGenMfMaleKpDp2);

 MNLLHarvGenMfMaleKpD=sum(MLHarvGenMfMaleKpDYr);

 // for General Modern firearm Female

 MHarvGenMfFmaleKpD=elem\_prod(MDoePop,DatHarvGenMfFmaleSeas)\*PHarvGenMfGenVuln;

 MLHarvGenMfFmaleKpDp1=log(pow(1/(sqrt(2\*M\_PI)\*elem\_prod(DatHarvGenMfFmaleKpDSE,DatHarvGenMfFmaleKpD)), DatHarvGenMfFmaleSeas));

 MLHarvGenMfFmaleKpDp2=elem\_prod(elem\_div(-square(log(DatHarvGenMfFmaleKpD+pow(10,-100))-log(MHarvGenMfFmaleKpD+pow(10,-100))),2\*square(DatHarvGenMfFmaleKpDSE)+pow(10,-100)), DatHarvGenMfFmaleSeas);

 MLHarvGenMfFmaleKpDYr=-(MLHarvGenMfFmaleKpDp1+MLHarvGenMfFmaleKpDp2);

 MNLLHarvGenMfFmaleKpD=sum(MLHarvGenMfFmaleKpDYr);

 //for General Muzzleloader Male

 MHarvGenMzMaleKpD=elem\_prod(MBuckPop,DatHarvGenMzMaleSeas)\*PHarvGenMzGenMaleVuln;

 MLHarvGenMzMaleKpDp1=log(pow(1/(sqrt(2\*M\_PI)\*elem\_prod(DatHarvGenMzMaleKpDSE,DatHarvGenMzMaleKpD)), DatHarvGenMzMaleSeas));

 MLHarvGenMzMaleKpDp2=elem\_prod(elem\_div(-square(log(DatHarvGenMzMaleKpD+pow(10,-100))-log(MHarvGenMzMaleKpD+pow(10,-100))),2\*square(DatHarvGenMzMaleKpDSE)+pow(10,-100)), DatHarvGenMzMaleSeas);

 MLHarvGenMzMaleKpDYr=-(MLHarvGenMzMaleKpDp1+MLHarvGenMzMaleKpDp2);

 MNLLHarvGenMzMaleKpD=sum(MLHarvGenMzMaleKpDYr);

 //for General Muzzleloader Female

 MHarvGenMzFmaleKpD=elem\_prod(MBuckPop,DatHarvGenMzFmaleSeas)\*PHarvGenMzGenFmaleVuln;

 MLHarvGenMzFmaleKpDp1=log(pow(1/(sqrt(2\*M\_PI)\*elem\_prod(DatHarvGenMzFmaleKpDSE,DatHarvGenMzFmaleKpD)), DatHarvGenMzFmaleSeas));

 MLHarvGenMzFmaleKpDp2=elem\_prod(elem\_div(-square(log(DatHarvGenMzFmaleKpD+pow(10,-100))-log(MHarvGenMzFmaleKpD+pow(10,-100))),2\*square(DatHarvGenMzFmaleKpDSE)+pow(10,-100)), DatHarvGenMzFmaleSeas);

 MLHarvGenMzFmaleKpDYr=-(MLHarvGenMzFmaleKpDp1+MLHarvGenMzFmaleKpDp2);

 MNLLHarvGenMzFmaleKpD=sum(MLHarvGenMzFmaleKpDYr);

 //Total

 NLLTot = MNLLHarvGenArMaleKpD + MNLLHarvGenArFmaleKpD +

 MNLLHarvGenMfMaleKpD + MNLLHarvGenMfFmaleKpD +

 MNLLHarvGenMzMaleKpD + MNLLHarvGenMzFmaleKpD +

 MPopLTHarvPenalty;

 Debug();

FUNCTION Debug

 if(OptCounter==1){

 cout << "OptCounter,"<<OptCounter<<endl;

 cout<<"Data"<<endl;

 cout<<" DatHarvGenArGenSeas= "<<DatHarvGenArGenSeas<<endl;

 cout<<" DatHarvGenArMaleSeas= "<<DatHarvGenArMaleSeas<<endl;

 cout<<" DatHarvGenArFmaleSeas= "<<DatHarvGenArFmaleSeas<<endl;

 cout<<" DatHarvGenArEffort= "<<DatHarvGenArEffort<<endl;

 cout<<" DatHarvGenArMaleHarv= "<<DatHarvGenArMaleHarv<<endl;

 cout<<" DatHarvGenArFmaleHarv= "<<DatHarvGenArFmaleHarv<<endl;

 cout<<" DatHarvGenArMaleKpD= "<<DatHarvGenArMaleKpD<<endl;

 cout<<" DatHarvGenArMaleKpDSE= "<<DatHarvGenArMaleKpDSE<<endl;

 cout<<" DatHarvGenArFmaleKpD= "<<DatHarvGenArFmaleKpD<<endl;

 cout<<" DatHarvGenArFmaleKpDSE= "<<DatHarvGenArFmaleKpDSE<<endl;

 cout<<" DatHarvGenMfGenSeas= "<<DatHarvGenMfGenSeas<<endl;

 cout<<" DatHarvGenMfMaleSeas= "<<DatHarvGenMfMaleSeas<<endl;

 cout<<" DatHarvGenMfFmaleSeas= "<<DatHarvGenMfFmaleSeas<<endl;

 cout<<" DatHarvGenMfEffort= "<<DatHarvGenMfEffort<<endl;

 cout<<" DatHarvGenMfMaleHarv= "<<DatHarvGenMfMaleHarv<<endl;

 cout<<" DatHarvGenMfFmaleHarv= "<<DatHarvGenMfFmaleHarv<<endl;

 cout<<" DatHarvGenMfMaleKpD= "<<DatHarvGenMfMaleKpD<<endl;

 cout<<" DatHarvGenMfMaleKpDSE= "<<DatHarvGenMfMaleKpDSE<<endl;

 cout<<" DatHarvGenMfFmaleKpD= "<<DatHarvGenMfFmaleKpD<<endl;

 cout<<" DatHarvGenMfFmaleKpDSE= "<<DatHarvGenMfFmaleKpDSE<<endl;

 cout<<" DatHarvGenMzGenSeas= "<<DatHarvGenMzGenSeas<<endl;

 cout<<" DatHarvGenMzMaleSeas= "<<DatHarvGenMzMaleSeas<<endl;

 cout<<" DatHarvGenMzFmaleSeas= "<<DatHarvGenMzFmaleSeas<<endl;

 cout<<" DatHarvGenMzEffort= "<<DatHarvGenMzEffort<<endl;

 cout<<" DatHarvGenMzMaleHarv= "<<DatHarvGenMzMaleHarv<<endl;

 cout<<" DatHarvGenMzFmaleHarv= "<<DatHarvGenMzFmaleHarv<<endl;

 cout<<" DatHarvGenMzMaleKpD= "<<DatHarvGenMzMaleKpD<<endl;

 cout<<" DatHarvGenMzMaleKpDSE= "<<DatHarvGenMzMaleKpDSE<<endl;

 cout<<" DatHarvGenMzFmaleKpD= "<<DatHarvGenMzFmaleKpD<<endl;

 cout<<" DatHarvGenMzFmaleKpDSE= "<<DatHarvGenMzFmaleKpDSE<<endl;

 cout<<" DatHarvPmtMinorHad= "<<DatHarvPmtMinorHad<<endl;

 cout<<" DatHarvPmtMinorPmts= "<<DatHarvPmtMinorPmts<<endl;

 cout<<" DatHarvPmtMinorMaleHarv= "<<DatHarvPmtMinorMaleHarv<<endl;

 cout<<" DatHarvPmtMinorFmaleHarv= "<<DatHarvPmtMinorFmaleHarv<<endl;

 cout<<" DatHarvPmtMfMfHad= "<<DatHarvPmtMfMfHad<<endl;

 cout<<" DatHarvPmtMfMfPmts= "<<DatHarvPmtMfMfPmts<<endl;

 cout<<" DatHarvPmtMfMfMaleHarv= "<<DatHarvPmtMfMfMaleHarv<<endl;

 cout<<" DatHarvPmtMfMfFmaleHarv= "<<DatHarvPmtMfMfFmaleHarv<<endl;

 cout<<" DatHarvPmtMfYoHad= "<<DatHarvPmtMfYoHad<<endl;

 cout<<" DatHarvPmtMfYoPmts= "<<DatHarvPmtMfYoPmts<<endl;

 cout<<" DatHarvPmtMfYoMaleHarv= "<<DatHarvPmtMfYoMaleHarv<<endl;

 cout<<" DatHarvPmtMfYoFmaleHarv= "<<DatHarvPmtMfYoFmaleHarv<<endl;

 cout<<" DatHarvPmtMzAlHad= "<<DatHarvPmtMzAlHad<<endl;

 cout<<" DatHarvPmtMzAlPmts= "<<DatHarvPmtMzAlPmts<<endl;

 cout<<" DatHarvPmtMzAlMaleHarv= "<<DatHarvPmtMzAlMaleHarv<<endl;

 cout<<" DatHarvPmtMzAlFmaleHarv= "<<DatHarvPmtMzAlFmaleHarv<<endl;

 cout<<" DatMaleTotHarv= "<<DatMaleTotHarv<<endl;

 cout<<" Sum DatMaleTotHarv= "<<sum(DatMaleTotHarv)<<endl;

 cout<<" DatFmaleTotHarv= "<<DatFmaleTotHarv<<endl;

 cout<<" Sum DatFmaleTotHarv= "<<sum(DatFmaleTotHarv)<<endl;

 cout<<"Parameters"<<endl;

 cout<<" PFPSFpD= "<<PFPSFpD<<endl;

 cout<<" PMPSFpD= "<<PMPSFpD<<endl;

 cout<<" PJuvFNatSurv= "<<PJuvFNatSurv<<endl;

 cout<<" PJuvMNatSurv= "<<PJuvMNatSurv<<endl;

 cout<<" PDoeNatSurv= "<<PDoeNatSurv<<endl;

 cout<<" PBuckNatSurv= "<<PBuckNatSurv<<endl;

 cout<<" PJuvFYr1= "<<PJuvFYr1<<endl;

 cout<<" PJuvMYr1= "<<PJuvMYr1<<endl;

 cout<<" PDoeYr1= "<<PDoeYr1<<endl;

 cout<<" PBuckYr1= "<<PBuckYr1<<endl;

 cout<<" MJuvFPop= "<<MJuvFPop<<endl;

 cout<<" MJuvMPop= "<<MJuvMPop<<endl;

 cout<<" MDoePop= "<<MDoePop<<endl;

 cout<<" MBuckPop= "<<MBuckPop<<endl;

 cout<<" MHarvGenArMaleKpD= "<<MHarvGenArMaleKpD<<endl;

 cout<<" DatHarvGenArEffort= "<<DatHarvGenArEffort<<endl;

 cout<<" DatHarvGenArMaleSeas= "<<DatHarvGenArMaleSeas<<endl;

 cout<<" PHarvGenArGenVuln= "<<PHarvGenArGenVuln<<endl;

 cout<<" DatHarvGenArMaleKpD= "<<DatHarvGenArMaleKpD<<endl;

 cout<<" DatHarvGenArMaleKpDSE= "<<DatHarvGenArMaleKpDSE<<endl;

 cout<<" MLHarvGenArMaleKpDp1= "<<MLHarvGenArMaleKpDp1<<endl;

 cout<<" MLHarvGenArMaleKpDp2= "<<MLHarvGenArMaleKpDp2<<endl;

 cout<<" MLHarvGenArMaleKpDYr= "<<MLHarvGenArMaleKpDYr<<endl;

 cout<<" MNLLHarvGenArMaleKpD= "<<MNLLHarvGenArMaleKpD<<endl;

 cout<<" MHarvGenArFmaleKpD= "<<MHarvGenArFmaleKpD<<endl;

 cout<<" DatHarvGenArEffort= "<<DatHarvGenArEffort<<endl;

 cout<<" DatHarvGenArFmaleSeas= "<<DatHarvGenArFmaleSeas<<endl;

 cout<<" PHarvGenArGenVuln= "<<PHarvGenArGenVuln<<endl;

 cout<<" DatHarvGenArFmaleKpD= "<<DatHarvGenArFmaleKpD<<endl;

 cout<<" DatHarvGenArFmaleKpDSE= "<<DatHarvGenArFmaleKpDSE<<endl;

 cout<<" MLHarvGenArFmaleKpDp1= "<<MLHarvGenArFmaleKpDp1<<endl;

 cout<<" MLHarvGenArFmaleKpDp2= "<<MLHarvGenArFmaleKpDp2<<endl;

 cout<<" MLHarvGenArFmaleKpDYr= "<<MLHarvGenArFmaleKpDYr<<endl;

 cout<<" MNLLHarvGenArFmaleKpD= "<<MNLLHarvGenArFmaleKpD<<endl;

 cout<<" MHarvGenMfMaleKpD= "<<MHarvGenMfMaleKpD<<endl;

 cout<<" DatHarvGenMfEffort= "<<DatHarvGenMfEffort<<endl;

 cout<<" DatHarvGenMfMaleSeas= "<<DatHarvGenMfMaleSeas<<endl;

 cout<<" PHarvGenMfGenVuln= "<<PHarvGenMfGenVuln<<endl;

 cout<<" DatHarvGenMfMaleKpD= "<<DatHarvGenMfMaleKpD<<endl;

 cout<<" DatHarvGenMfMaleKpDSE= "<<DatHarvGenMfMaleKpDSE<<endl;

 cout<<" MLHarvGenMfMaleKpDp1= "<<MLHarvGenMfMaleKpDp1<<endl;

 cout<<" MLHarvGenMfMaleKpDp2= "<<MLHarvGenMfMaleKpDp2<<endl;

 cout<<" MLHarvGenMfMaleKpDYr= "<<MLHarvGenMfMaleKpDYr<<endl;

 cout<<" MNLLHarvGenMfMaleKpD= "<<MNLLHarvGenMfMaleKpD<<endl;

 cout<<" MHarvGenMfFmaleKpD= "<<MHarvGenMfFmaleKpD<<endl;

 cout<<" DatHarvGenArEffort= "<<DatHarvGenArEffort<<endl;

 cout<<" DatHarvGenMfFmaleSeas= "<<DatHarvGenMfFmaleSeas<<endl;

 cout<<" PHarvGenMfGenVuln= "<<PHarvGenMfGenVuln<<endl;

 cout<<" DatHarvGenMfFmaleKpD= "<<DatHarvGenMfFmaleKpD<<endl;

 cout<<" DatHarvGenMfFmaleKpDSE= "<<DatHarvGenMfFmaleKpDSE<<endl;

 cout<<" MLHarvGenMfFmaleKpDp1= "<<MLHarvGenMfFmaleKpDp1<<endl;

 cout<<" MLHarvGenMfFmaleKpDp2= "<<MLHarvGenMfFmaleKpDp2<<endl;

 cout<<" MLHarvGenMfFmaleKpDYr= "<<MLHarvGenMfFmaleKpDYr<<endl;

 cout<<" MNLLHarvGenMfFmaleKpD= "<<MNLLHarvGenMfFmaleKpD<<endl;

 cout<<" MHarvGenMzMaleKpD= "<<MHarvGenMzMaleKpD<<endl;

 cout<<" DatHarvGenMzEffort= "<<DatHarvGenMzEffort<<endl;

 cout<<" DatHarvGenMzMaleSeas= "<<DatHarvGenMzMaleSeas<<endl;

 cout<<" PHarvGenMzGenMaleVuln= "<<PHarvGenMzGenMaleVuln<<endl;

 cout<<" DatHarvGenMzMaleKpD= "<<DatHarvGenMzMaleKpD<<endl;

 cout<<" DatHarvGenMzMaleKpDSE= "<<DatHarvGenMzMaleKpDSE<<endl;

 cout<<" MLHarvGenMzMaleKpDp1= "<<MLHarvGenMzMaleKpDp1<<endl;

 cout<<" MLHarvGenMzMaleKpDp2= "<<MLHarvGenMzMaleKpDp2<<endl;

 cout<<" MLHarvGenMzMaleKpDYr= "<<MLHarvGenMzMaleKpDYr<<endl;

 cout<<" MNLLHarvGenMzMaleKpD= "<<MNLLHarvGenMzMaleKpD<<endl;

 cout<<" MHarvGenMzFmaleKpD= "<<MHarvGenMzFmaleKpD<<endl;

 cout<<" DatHarvGenArEffort= "<<DatHarvGenArEffort<<endl;

 cout<<" DatHarvGenMzFmaleSeas= "<<DatHarvGenMzFmaleSeas<<endl;

 cout<<" PHarvGenMzGenFmaleVuln= "<<PHarvGenMzGenFmaleVuln<<endl;

 cout<<" DatHarvGenMzFmaleKpD= "<<DatHarvGenMzFmaleKpD<<endl;

 cout<<" DatHarvGenMzFmaleKpDSE= "<<DatHarvGenMzFmaleKpDSE<<endl;

 cout<<" MLHarvGenMzFmaleKpDp1= "<<MLHarvGenMzFmaleKpDp1<<endl;

 cout<<" MLHarvGenMzFmaleKpDp2= "<<MLHarvGenMzFmaleKpDp2<<endl;

 cout<<" MLHarvGenMzFmaleKpDYr= "<<MLHarvGenMzFmaleKpDYr<<endl;

 cout<<" MNLLHarvGenMzFmaleKpD= "<<MNLLHarvGenMzFmaleKpD<<endl;

 }

RUNTIME\_SECTION

 //convergence\_criteria 0.0000001

 maximum\_function\_evaluations 3000

REPORT\_SECTION

 report<<" OptCounter= "<<OptCounter<<endl;

 report<<" PFPSFpD= "<<PFPSFpD <<endl;

 report<<" PMPSFpD= "<<PMPSFpD <<endl;

 report<<" PJuvFNatSurv= "<<PJuvFNatSurv <<endl;

 report<<" PJuvMNatSurv= "<<PJuvMNatSurv <<endl;

 report<<" PDoeNatSurv= "<<PDoeNatSurv <<endl;

 report<<" PBuckNatSurv= "<<PBuckNatSurv <<endl;

 report<<" PJuvFYr1= "<<PJuvFYr1 <<endl;

 report<<" PJuvMYr1= "<<PJuvMYr1 <<endl;

 report<<" PDoeYr1= "<<PDoeYr1 <<endl;

 report<<" PBuckYr1= "<<PBuckYr1 <<endl;

 report<<" MJuvFPop= "<<MJuvFPop<<endl;

 report<<" MJuvMPop= "<<MJuvMPop<<endl;

 report<<" MDoePop= "<<MDoePop<<endl;

 report<<" MBuckPop= "<<MBuckPop<<endl;

 report<<" DatFmaleTotHarv= "<<DatFmaleTotHarv<<endl;

 report<<" DatMaleTotHarv= "<<DatMaleTotHarv<<endl;

 report<<" MHarvGenArMaleKpD= "<<MHarvGenArMaleKpD<<endl;

 report<<" DatHarvGenArEffort= "<<DatHarvGenArEffort<<endl;

 report<<" DatHarvGenArMaleSeas= "<<DatHarvGenArMaleSeas<<endl;

 report<<" PHarvGenArGenVuln= "<<PHarvGenArGenVuln<<endl;

 report<<" DatHarvGenArMaleKpD= "<<DatHarvGenArMaleKpD<<endl;

 report<<" DatHarvGenArMaleKpDSE= "<<DatHarvGenArMaleKpDSE<<endl;

 report<<" MLHarvGenArMaleKpDp1= "<<MLHarvGenArMaleKpDp1<<endl;

 report<<" MLHarvGenArMaleKpDp2= "<<MLHarvGenArMaleKpDp2<<endl;

 report<<" MNLLHarvGenArMaleKpD= "<<MNLLHarvGenArMaleKpD<<endl;

 report<<" MHarvGenArFmaleKpD= "<<MHarvGenArFmaleKpD<<endl;

 report<<" DatHarvGenArEffort= "<<DatHarvGenArEffort<<endl;

 report<<" DatHarvGenArFmaleSeas= "<<DatHarvGenArFmaleSeas<<endl;

 report<<" PHarvGenArGenVuln= "<<PHarvGenArGenVuln<<endl;

 report<<" DatHarvGenArFmaleKpD= "<<DatHarvGenArFmaleKpD<<endl;

 report<<" DatHarvGenArFmaleKpDSE= "<<DatHarvGenArFmaleKpDSE<<endl;

 report<<" MLHarvGenArFmaleKpDp1= "<<MLHarvGenArFmaleKpDp1<<endl;

 report<<" MLHarvGenArFmaleKpDp2= "<<MLHarvGenArFmaleKpDp2<<endl;

 report<<" MNLLHarvGenArFmaleKpD= "<<MNLLHarvGenArFmaleKpD<<endl;

 report<<" MHarvGenMfMaleKpD= "<<MHarvGenMfMaleKpD<<endl;

 report<<" DatHarvGenMfEffort= "<<DatHarvGenMfEffort<<endl;

 report<<" DatHarvGenMfMaleSeas= "<<DatHarvGenMfMaleSeas<<endl;

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 report<<" DatHarvGenMfMaleKpD= "<<DatHarvGenMfMaleKpD<<endl;

 report<<" DatHarvGenMfMaleKpDSE= "<<DatHarvGenMfMaleKpDSE<<endl;

 report<<" MLHarvGenMfMaleKpDp1= "<<MLHarvGenMfMaleKpDp1<<endl;

 report<<" MLHarvGenMfMaleKpDp2= "<<MLHarvGenMfMaleKpDp2<<endl;

 report<<" MNLLHarvGenMfMaleKpD= "<<MNLLHarvGenMfMaleKpD<<endl;

 report<<" MHarvGenMfFmaleKpD= "<<MHarvGenMfFmaleKpD<<endl;

 report<<" DatHarvGenMfEffort= "<<DatHarvGenMfEffort<<endl;

 report<<" DatHarvGenMfFmaleSeas= "<<DatHarvGenMfFmaleSeas<<endl;

 report<<" PHarvGenMfGenVuln= "<<PHarvGenMfGenVuln<<endl;

 report<<" DatHarvGenMfFmaleKpD= "<<DatHarvGenMfFmaleKpD<<endl;

 report<<" DatHarvGenMfFmaleKpDSE= "<<DatHarvGenMfFmaleKpDSE<<endl;

 report<<" MLHarvGenMfFmaleKpDp1= "<<MLHarvGenMfFmaleKpDp1<<endl;

 report<<" MLHarvGenMfFmaleKpDp2= "<<MLHarvGenMfFmaleKpDp2<<endl;

 report<<" MNLLHarvGenMfFmaleKpD= "<<MNLLHarvGenMfFmaleKpD<<endl;

 report<<" MHarvGenMzMaleKpD= "<<MHarvGenMzMaleKpD<<endl;

 report<<" DatHarvGenMzEffort= "<<DatHarvGenMzEffort<<endl;

 report<<" DatHarvGenMzMaleSeas= "<<DatHarvGenMzMaleSeas<<endl;

 report<<" PHarvGenMzGenMaleVuln= "<<PHarvGenMzGenMaleVuln<<endl;

 report<<" DatHarvGenMzMaleKpD= "<<DatHarvGenMzMaleKpD<<endl;

 report<<" DatHarvGenMzMaleKpDSE= "<<DatHarvGenMzMaleKpDSE<<endl;

 report<<" MLHarvGenMzMaleKpDp1= "<<MLHarvGenMzMaleKpDp1<<endl;

 report<<" MLHarvGenMzMaleKpDp2= "<<MLHarvGenMzMaleKpDp2<<endl;

 report<<" MNLLHarvGenMzMaleKpD= "<<MNLLHarvGenMzMaleKpD<<endl;

 report<<" MHarvGenMzFmaleKpD= "<<MHarvGenMzFmaleKpD<<endl;

 report<<" DatHarvGenMzEffort= "<<DatHarvGenMzEffort<<endl;

 report<<" DatHarvGenMzFmaleSeas= "<<DatHarvGenMzFmaleSeas<<endl;

 report<<" PHarvGenMzGenFmaleVuln= "<<PHarvGenMzGenFmaleVuln<<endl;

 report<<" DatHarvGenMzFmaleKpD= "<<DatHarvGenMzFmaleKpD<<endl;

 report<<" DatHarvGenMzFmaleKpDSE= "<<DatHarvGenMzFmaleKpDSE<<endl;

 report<<" MLHarvGenMzFmaleKpDp1= "<<MLHarvGenMzFmaleKpDp1<<endl;

 report<<" MLHarvGenMzFmaleKpDp2= "<<MLHarvGenMzFmaleKpDp2<<endl;

 report<<" MNLLHarvGenMzFmaleKpD= "<<MNLLHarvGenMzFmaleKpD<<endl;

 report<<" MPopLTHarvPenYr= "<<MPopLTHarvPenYr<<endl;

 report<<" MPopLTHarvPenalty= "<<MPopLTHarvPenalty<<endl;

 report<<" NLLTot= "<<NLLTot<<endl;

 report<<endl;

 report<<" Archery Male"<<" PHarvGenArGenVuln= "<<PHarvGenArGenVuln<<" MHarvGenArMaleKpD= "<<MHarvGenArMaleKpD<<endl;

 report<<" Archery Female"<<" PHarvGenArGenVuln= "<<PHarvGenArGenVuln<<" MHarvGenArFmaleKpD= "<<MHarvGenArFmaleKpD<<endl;

 report<<endl;

 report<<" Modern firearm Male "<<endl;

 report<<" DatHarvGenMfMaleKpD= "<<DatHarvGenMfMaleKpD<<endl;

 report<<" MHarvGenMfMaleKpD= "<<MHarvGenMfMaleKpD<<endl;

 report<<" Modern firearm Female "<<endl;

 report<<" DatHarvGenMfFmaleKpD= "<<DatHarvGenMfFmaleKpD<<endl;

 report<<" MHarvGenMfFmaleKpD= "<<MHarvGenMfFmaleKpD<<endl;

 report<<" Muzzleloader Male "<<endl;

 report<<" DatHarvGenMzMaleKpD= "<<DatHarvGenMzMaleKpD<<endl;

 report<<" MHarvGenMzMaleKpD= "<<MHarvGenMzMaleKpD<<endl;

 report<<" Muzzleloader Female "<<endl;

 report<<" DatHarvGenMzFmaleKpD= "<<DatHarvGenMzFmaleKpD<<endl;

 report<<" MHarvGenMzFmaleKpD= "<<MHarvGenMzFmaleKpD<<endl;

1. AD Model Builder. http://www.admb-project.org/ [↑](#footnote-ref-1)
2. Harvest Estimation Based on Mandatory Reporting Deer and Elk Analysis Plan [↑](#footnote-ref-2)
3. PBSadmb User's Guide. <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=2&cad=rja&ved=0CC8QFjAB&url=http%3A%2F%2Fpbs-software.googlecode.com%2Ffiles%2FPBSadmb-UG-v04.pdf&ei=t7NNUt_SD-OSiAKmyIGwAw&usg=AFQjCNGUgdIMkxSIa88DNXmVohQkePsoeA> [↑](#footnote-ref-3)