PGC Photo – H. Korber

MONITORING DEER POPULATIONS IN PENNSYLVANIA

January 2011

Monitoring Deer Populations In Pennsylvania

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Executive Summary

In 2005, Game Commission (PGC) biologists and researchers from the Cooperative Fish and Wildlife Research Unit (PCFWRU) at Penn State University developed the Pennsylvania sex-age-kill model (PASAK). This model was developed to monitor deer population trends. Model results were not intended to be estimates of actual deer populations because of a number of necessary assumptions in the model. In addition, the model had no measures of variation associated with it.

Following development, the model was sent to biologists and biometricians in other states and Canadian provinces for review. Following these reviews, a thorough evaluation of the model was conducted by the PGC and PCFWRU. This evaluation included investigations of model performance, sensitivity to data inputs, and development of measures of variation. This evaluation was completed in August 2010.

In addition to requested peer-reviews and PGC/PCFWRU investigations, the PASAK model was reviewed by the Wildlife Management Institute (WMI) as part of their legislatively-sponsored review and evaluation of the deer program. Following their evaluation, WMI concluded that:

"The PGC has developed a credible model that factors in necessary adjustments to reflect antler restrictions. WMI also documented that the PGC strives continually to improve the precision of the model inputs by conducting field research. All parties interested in deer management in Pennsylvania can be confident in the ability of the PGC to track deer population trends at the statewide and WMU scales through the use of the PA SAK as long as PGC data collection thresholds for data input are met or exceeded."

The Wildlife Management Institute also made a number of recommendations to improve the PASAK model:

1. Continue to test and improve the model
2. Discontinue the practice of updating model inputs with reconstructed antlered populations
3. Prioritize research to better understand variation in subadult male harvest rates
4. Discontinue the practice of updating juvenile to mature female ratios with reconstructed populations
5. Incorporate DMAP antlerless harvest into the PASAK model
6. Release population estimates and measures of variation to the public

Following the conclusion of the PGC/PCFWRU and WMI evaluations, the PASAK model was updated. All of the WMI's short-term recommendations were incorporated into the PASAK model and field research continues to address WMI's long-term recommendations. Release of population estimates with measures of variation is also possible following the conclusion of Game Commission/Cooperative Research Unit evaluation.

The PASAK model accomplishes its purpose of monitoring population trends, but assumptions limit results to relative WMU estimates. Higher reporting rates and continued data collection will improve the PASAK model.

Acknowledgements

Many people including employees of the Pennsylvania Game Commission, Pennsylvania Cooperative Fish and Wildlife Research Unit staff at Pennsylvania State University, undergraduate and graduate students and volunteers helped to collect the data and information presented in this document. All data contained herein are subject to revision from corrections, improved analyses, and/or regrouping of data.

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1. Introduction to Deer Population Monitoring in Pennsylvania

How many deer are in the photo on the cover? The cover photo represents a best-case scenario – a still photograph of brown-coated deer in an open, snow-covered landscape. With time and a keen eye, one may see the 8 deer present in this photo. If it is difficult to count all the deer in a photograph, consider the difficulty in counting deer in the real world across the state of Pennsylvania, especially when that number is changing every day.

In a perfect deer management program, deer biologists would know exactly how many deer were in an area. All successful hunters would accurately report their deer harvests. And, relationships between deer populations and the environment would be known with certainty. Unfortunately, the Pennsylvania Game Commission does not manage deer in a perfect world.

It is impossible to count all the deer in Pennsylvania and no amount of desire will change this reality (Andrewartha 1961, White 2000). White-tailed deer are secretive, well camouflaged, and always difficult to count (Rice and Harder 1977, Ludwig 1981, Stoll et al. 1991, Beringer et al. 1998). Thus, most wildlife agencies monitor relative abundance, not absolute or actual numbers of deer, by analyzing deer harvest data (Creed et al. 1984, Roseberry and Woolf 1991). When monitoring relative abundance, the most important consideration is whether the deer population trend is increasing, decreasing, or stable; not how many deer are in an area.

Deer biologists often use mathematical models to monitor deer populations. A model combines various data inputs – for example, age and sex of deer and number of deer harvested – to generate a representation of the population. A model provides an estimate of deer abundance, not an absolute count. Often, available data will limit interpretation of model results to represent relative changes in deer numbers (i.e., population abundance is increasing, decreasing, or stable).

Deer numbers, although a part of the PGC's deer program, are not the primary management consideration. Deer impacts – not deer numbers – define the PGC's deer management goals and objectives. Rather than setting management objectives based on the number of deer in an area, management objectives are defined by deer health, forest habitat health, and deer-human conflicts measures. These measures, in conjunction with measures of deer population trends, form the basis for deer management recommendations.

The PGC and PCFWRU developed the PASAK model in 2005 to monitor deer population trends. The PASAK model is a sex-age-kill model (Eberhardt 1960, Creed et al. 1984, Skalski and Millspaugh 2002) with modifications for antler restrictions. When the PASAK model was subjected to a recent external review, it was determined to be a credible model for tracking population trends thereby fulfilling its intended function (Wildlife Management Institute 2010).

Since the PASAK model was developed, the PGC has emphasized the limitations and purpose of the model. The following passage has appeared in deer population annual reports posted on the PGC's website (www.pgc.state.pa.us) since 2006:

> *When interpreting results from the modified SAK [i.e., PASAK model] procedure, it is important to know that due to the nature of population reconstruction methods, such as those used in the SAK procedure, the most accurate population estimate for a particular year occurs at some point in the future when data for each cohort of deer is complete (Skalski et al. 2005). Consequently, for the most recent years, population numbers should be viewed as indices rather than estimates (Skalski et al. 2005). Second, due to necessary assumptions of this population monitoring procedure, population numbers used to assess*

trends should be viewed as relative (i.e., whether trends are increasing, decreasing, or remaining stable), not absolute numbers. As we accumulate more years of data and results from ongoing internal and external evaluations, refinements to this procedure will occur.

Changes in the PASAK model have occurred. However, assumptions remain that prevent the PASAK from estimating absolute numbers of deer in a WMU or statewide.

The PASAK model contains assumptions. Assumptions are needed because data necessary to determine annual deer numbers across large areas are typically not available as a result of time, money, and personnel constraints (Roseberry and Woolf 1991, White 2000, Morrellet et al. 2007). When working with assumptions, maintaining consistency in procedures and controllable variables is critical. For a hunted species, an important controllable variable would be maintaining consistent hunting regulations. When regulations change, uncertainty surrounding assumptions increases.

Rather than accept assumptions, the PGC continues to investigate performance of the PASAK model and evaluate assumptions. Since its initial development, the PASAK model has been subjected to external reviews and internal evaluations to assess its utility and reliability (See PASAK Model Timeline below). In addition, the PASAK model was reviewed recently as part of an evaluation sponsored by the Legislative Budget and Finance Committee (LBFC, Wildlife Management Institute 2010).

PASAK Model Timeline

2005 – PASAK model developed by PGC deer biologists and researchers at the Pennsylvania Cooperative Fish and Wildlife Research Unit (PCFWRU) at Penn State University

2006 – PGC deer biologists send PASAK model out for reviews by biologists and biometricians from 9 states, 1 Canadian province, and the U.S. Fish and Wildlife Service.

2007 – Based in part on findings from the 2006 peer-review, PGC and PCFWRU start in-depth evaluation of PASAK model precision, sensitivity, and assumptions

2008 – LBFC approves audit of deer management program and PASAK.

2009 – Wildlife Management Institute (WMI) conducts audit of PGC deer program and PASAK.

2009 – PCFWRU provides interim report to WMI of ongoing evaluations of PASAK.

2010 – WMI releases its report stating the PASAK model is a credible method of tracking deer population trends. WMI's report contains population estimates from PCFWRU interim report.

2010 – The PGC/PCFWRU evaluations of the PASAK model are completed.

2010 – The PGC and PCFWRU modify the PASAK model to reflect findings from evaluations and recommendations from WMI.

Present (January 2011) – The PGC and PCFWRU continue to evaluate assumptions of the PASAK model using marked deer in 4 WMUs and computer simulation.

The PASAK model can provide deer population trend information without providing absolute deer numbers. For example, assume a constant adult male harvest rate for all WMUs. If the harvest rate is higher in one WMU compared to the constant harvest rate, it will lead to differences in the number of deer. However, if the harvest rate is consistent over time the estimated trend will follow the actual trend (Example 1). As shown in this example, it is possible to reliably track deer population trends even if the estimated population is not the same as the actual population. Likewise, presence of assumptions in the PASAK model prevent the PGC from saying there are a specific number of deer in a WMU, but do not necessarily prevent tracking of deer population trends.

Example 1. Adult male harvest rate assumption

Assume 50 percent of adult males are harvested. A harvest of 100 would result in a population estimate of 200 adult males because,

$$Population = \frac{Harvest}{Harvest\ Rate}$$

$$Population = \frac{100}{0.50}$$

$$Population = 200\ adult\ males$$

If the actual harvest rate is 60 percent, the actual population will be 167 adult males.

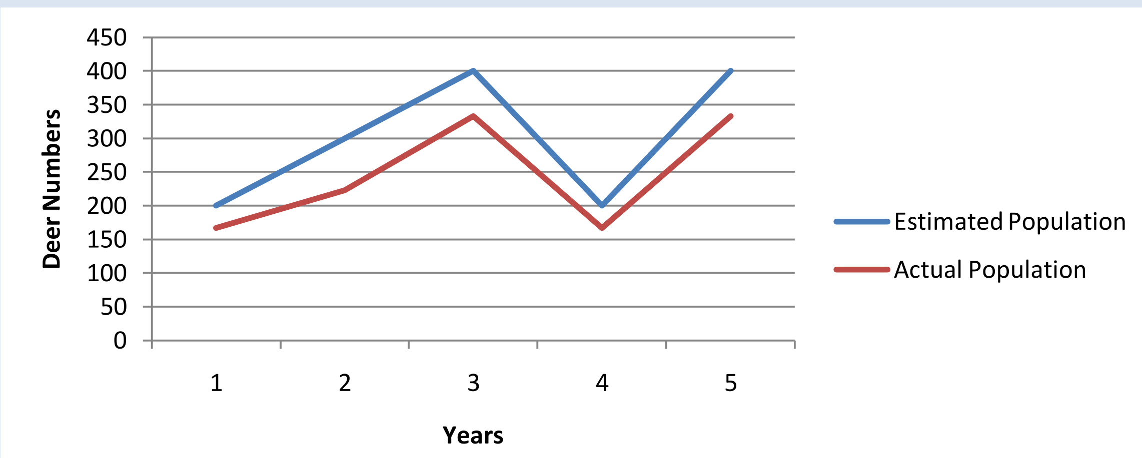
$$Population = \frac{100}{0.60}$$

$$Population = 167\ adult\ males$$

As a result, the estimate is higher (i.e. 200 adult males) than the actual number (i.e. 167 adult males).

If the harvest rate is consistently 60 percent over time, then the trend will be consistent with the population.

Year	Harvest	Estimated population assuming 50% harvest rate	Actual population
1	100	200	167
2	150	300	223
3	200	400	333
4	100	200	167
5	200	400	333



2. Questions about Deer Population Estimates

1. **How many deer are there in Pennsylvania?**

   Nobody knows because it is impossible to count every deer in the state. The Pennsylvania Game Commission (PGC) uses a modified sex-age-kill model to estimate deer population trends. The model is based on data from hunters, harvested and research deer, and hunter surveys. It is not used to determine the absolute number of deer in the state.

2. **How can the PGC manage deer without knowing the number of deer?**

   Like other states, the PGC monitors deer populations by tracking trends. Deer management recommendations are made to increase, decrease, or stabilize those trends. To make recommendations, the actual number of deer in a wildlife management unit (WMU) is not needed.

3. **But, if the PGC doesn't know how many deer there are, isn't there a chance too many deer will be harvested?**

   Not if seasons and harvests are carefully and incrementally managed and key indices monitored. Consistent season structure and adjustment of antlerless allocations has proven successful in Pennsylvania for decades. By maintaining consistent regulations and making incremental adjustments in antlerless allocations, deer populations can be managed to meet objectives. There is no substitute for consistency when managing WMU deer populations. By adjusting one variable – such as the antlerless allocation – changes to the deer population occur in a more predictable way and can be monitored to avoid unwanted consequences.

4. **What do wildlife professionals outside the PGC say about deer population numbers and trends?**

   The wildlife profession has long recognized the difficulty in counting deer and other wildlife. The following quotes cover decades of comments from wildlife professionals on the need for absolute numbers in deer and wildlife management:

   "Sometimes technical difficulties may make it impossible to measure the absolute density of the population no matter how desireable this may be, and to estimate relative densities may be the best that one can do." (H.G. Andrewartha in Introduction to the Study of Animal Populations, 1961)

   "Estimates of abundance have no intrinsic value and they should never be considered ends in themselves. Many biological problems require no estimate of abundance. Other problems, particularly those linked with utilization of habitat, rate of increase, dispersal, and the reaction of a population to management treatments, can often be solved with estimates of relative density." (G. Caughley in Analysis of Vertebrate Populations, 1977)

   "Estimates of whitetail population size interest the public and appeal to the media. Often, however, the importance of knowing the population size is overestimated as a tool for deer management. It is more important to know the relative abundance of deer – whether the population is increasing or decreasing,

and whether it is above, below or nearly in balance with carrying capacity of the environment." (D. W. Hayne in Population Dynamics and Analysis chapter of White-tailed deer: Ecology and Management, 1984)

"I propose that it is time for management to abandon the quest for the absolute estimate, which is difficult or impossible to obtain and of limited use if known." (D. R. McCullough in Lessons from the George Reserve chapter of White-tailed deer: Ecology and Management, 1984)

"*Even if we assume that counts are accurate and precise, population size in itself provides no information on the relationship between the population and its habitat (e.g. density-dependence) with respect to given management objectives*." *(N. Morellet et al. in article published in Journal of Animal Ecology, 2007)*

The position of PGC wildlife managers that knowing the number of deer in a WMU is not needed to have sound deer management is consistent with findings from decades of wildlife research and management experience from around the world.

5. How does the PGC determine whether a trend is increasing, decreasing, or stable?

Population trends are identified as increasing, decreasing, or stable based on a statistical procedure that compares population estimates to each other over a period of 6 years. The specific test used by the PGC is the Mann-Kendall Test for Trend (Mann 1945, Kendall and Gibbons 1990).

6. Who developed the PASAK model?

In 2006, the PASAK model was developed jointly by PGC deer biologists and researchers at the Pennsylvania Cooperative Fish and Wildlife Research Unit (PCFWRU) at Penn State University.

7. How does the PASAK model work?

In simple terms, the PASAK model estimates the deer population in 4 steps. First, the antlered deer population is estimated using antlered harvest estimates and antlered harvest rates. Second, the mature female population (females at least 1 year of age) is estimated by multiplying the antlered population by the adult sex ratio. Third, the juvenile population is estimated by multiplying the mature female population by the fawn:doe ratio from the harvest. Finally, the total population is estimated by adding together the antlered population, the mature female population, and the juvenile population.

A detailed explanation of the PASAK model procedures begins on page 15.

8. Are PASAK estimates accurate?

A comparison between PASAK estimates and the actual number of deer in a WMU is not possible. As a result, accuracy of PASAK estimates cannot be determined.

9. **If you can't tell if the PASAK estimates are accurate, are they still useful?**

   Based on evaluations and an independent audit sponsored by the Legislature, the PASAK is a credible model for tracking deer population trends.

10. **Why are there 3 numbers for each WMU?**

    PASAK provides a point estimate and 90 percent confidence interval limits. Providing only the point estimate (ex. 49,985 deer) would imply exactness. PASAK estimates are not exact. A confidence interval is provided to convey variation associated with each estimate.

11. **What is a 90percent confidence interval?**

    A 90% confidence interval is a statistical measure of precision of a point estimate. The confidence interval is defined by a lower limit and an upper limit. These limits identify an interval for which there is 90% confidence that the interval includes the actual number of deer in a population. For example, if the lower limit is 10,000 and the upper limit is 20,000, one would be 90% confident the interval from 10,000 to 20,000 contained the actual population number.

12. **How good is the precision of the PASAK model estimates?**

    Based on common wildlife population estimation benchmarks, precision of PASAK population estimates achieve the benchmark for management surveys such as tracking deer population trends.

13. **Why do some of the point estimates increase or decrease a lot from year to year?**

    WMU 2G from 2005 to 2009 is a good example of dramatic annual changes. These changes may not reflect biologically possible population dynamics. For example, from 2005 to 2006 the antlered harvest in WMU 2G increased from 5,000 to 7,200 and the population estimate increased from 60,000 to 110,000. Then from 2008 to 2009, the population estimate dropped from 100,000 to 60,000 when the antlered harvest dropped from 6,800 to 5,200.

    The PASAK model is sensitive to changes in antlered harvests. This sensitivity demonstrates why the PGC limits its use of the PASAK model to tracking trends, not annual counts of deer in a WMU. By looking at the trend in deer population estimates over a number of years, management recommendations are not erroneously affected by large changes in point estimates from the PASAK model.

14. **Will smaller WMUs lead to better estimates?**

    Smaller WMUs will not improve the PASAK estimates. Sample sizes needed to estimate populations will only increase with more and smaller WMUs. Without an increase in data, variation of population estimates will increase. Collecting sufficient data for a large number of small management units is often not possible for wildlife agencies. This is why states such as Michigan and Wisconsin combine small management units into larger units for data analysis purposes.

15. How can precision of the PASAK estimates be improved?

More data will increase precision of the estimate and reduce the size of confidence intervals. Increased harvest reporting by hunters is the simplest method of adding data to the PASAK model. Continued field data collections also will improve the precision of PASAK estimates.

16. Why does the PASAK model have assumptions?

A deer population model is a mathematical representation of complex natural systems. Data cannot be collected on every individual deer or interaction between deer, habitat, and people. As a result, all deer population models have assumptions. For example, the PASAK model has the following assumptions:

a. Antlered harvest rates are related to hunter effort. This assumption is based on an analysis of observed harvest rates in 4 WMUs and hunter effort statistics. Based on this analysis, it is assumed the relationship between antlered harvest rates and hunter effort in these 4 WMUs is similar in other WMUs. Ongoing field studies in other WMUs will test the validity of this assumption.

b. Juveniles and mature females are harvested at the same rate. Mature females appear to be harvested at higher rates than juveniles. As a result, this assumption leads to underestimates of the population.

Personnel, time, and financial constraints will continue to require assumptions to compensate for gaps in field data. Much of the continuous evaluation of the PASAK focuses on strengthening critical assumptions.

Assumptions also prevent PASAK estimates from being used to represent the actual number of deer in a WMU. However, assumptions do not prevent the PASAK from tracking deer population trends.

17. Are PASAK estimates used to set antlerless allocations?

Yes, but the actual PASAK estimate (e.g., 49,985) is not used to calculate antlerless allocations. Antlerless allocations are based on WMU population trends. If the objective is to increase a deer population, the antlerless allocation will be reduced. If the objective is to decrease a deer population, the antlerless allocation will be increased. The population trend, not the number of deer, is critical to management recommendations. Management recommendations are based on trends over six years.

18. Has the PASAK model been reviewed and evaluated by other biologists?

Yes. The PASAK model was reviewed by biologists and biometricians from 9 states and 1 province in 2006. Based on comments from these reviews, the PGC and PCFWRU began an in-depth evaluation of the PASAK model in 2007. This evaluation was completed in August 2010. In addition, a Legislative Budget and Finance Committee-sponsored audit of the PASAK model was completed in February 2010.

19. What did the deer audit say about the PASAK model?

The auditors, provided by the Wildlife Management Institute (WMI) concluded that;

"The PGC has developed a credible model that factors in necessary adjustments to reflect antler restrictions. WMI also documented that the PGC strives continually to improve the precision of the model inputs by conducting field research. All parties interested in deer management in Pennsylvania can be confident in the ability of the PGC to track deer population trends at the statewide and WMU scales through the use of the PA SAK as long as PGC data collection thresholds for data input are met or exceeded." (page 60 of the audit report)

20. Did the PGC withhold deer population estimates as reported in the deer audit?

The deer population estimates in the audit (Appendix B, pages 80-81) came from a preliminary report of the PGC/PCFWRU's progress in evaluating the PASAK model that was requested by the auditors. These results were part of an ongoing study and were not used for management purposes.

Since the PGC began using the PASAK model for tracking deer population trends, population trend information has been released to the public in annual reports (Report 21001) available on the PGC's website, www.pgc.state.pa.us.

21. Why do current population estimates differ from Appendix B (pages 80-81) of the deer audit report?

The estimates in Appendix B of the deer audit are based on a preliminary report of PGC/PCFWRU's progress in evaluating the PASAK model. As noted on page 28 of the deer audit, these estimates were preliminary and subject to change. The PASAK model was modified based on the final results of the PGC/PCFWRU evaluation and recommendations from the deer audit report. These modifications led to recalculations in population estimates.

22. Will there be other modifications to the PASAK model in the future?

Yes. Current field studies are collecting more data on male and female harvest rates. These results will be used to improve the PGC's ability to monitor deer populations and likely lead to PASAK model updates.

23. Do PASAK estimates represent only hunted populations?

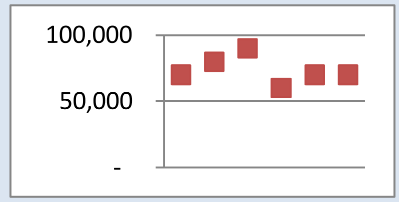
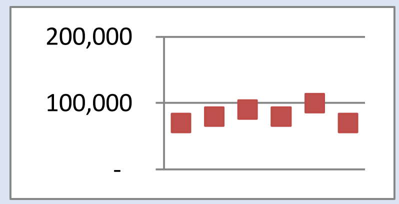
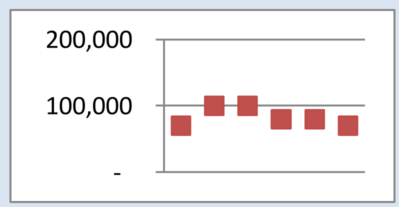
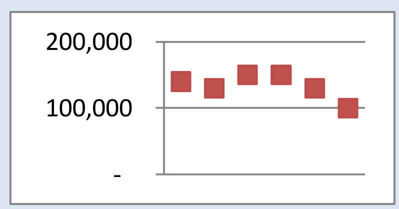
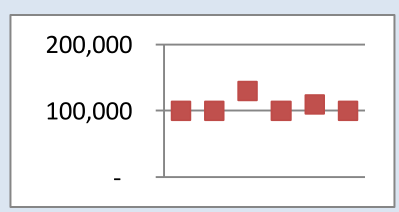
No. Unlike previous methods used by the PGC to estimate deer populations, the PASAK model includes data from deer on both hunted and unhunted land. Antlered harvest estimates are based on marked deer that are captured and then released. On average, the young bucks will travel 3 to 6 miles from where they were captured. Some will relocate to lands open to hunting; others to lands where no hunting occurs. The same is true for adult bucks. As a result, the antlered harvest rates represent a combination of animals from hunted and unhunted properties.

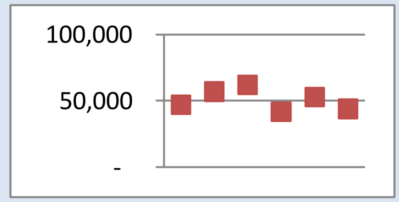
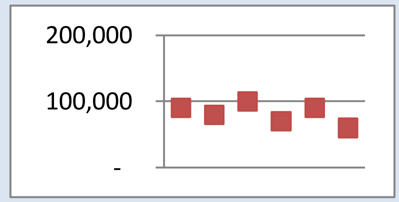
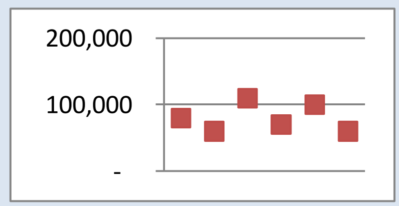
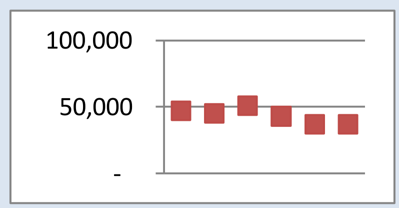
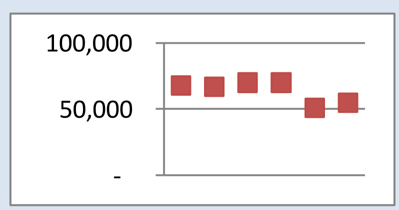
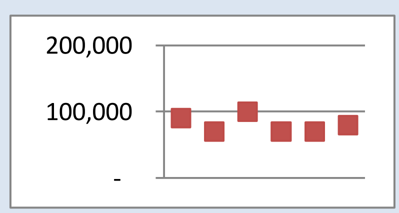
24. Where are the PASAK estimates for WMUs 2B, 5C, and 5D?

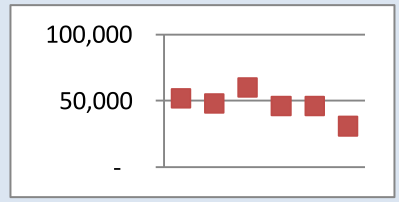
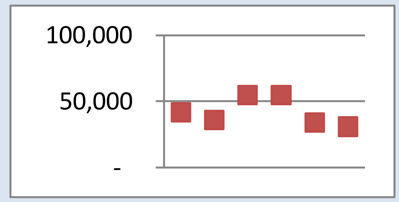
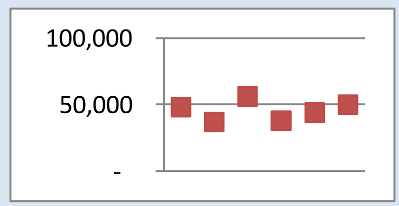
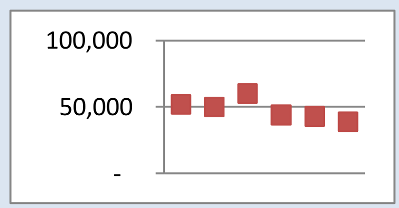
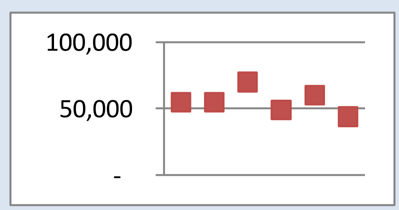
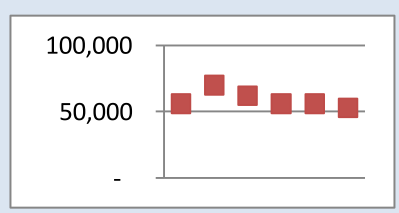
The PGC is not using the PASAK to estimate deer populations in WMUs 2B, 5C, and 5D. These WMUs are highly developed compared to other WMUs. The assumption regarding the relationship between hunter effort and antlered harvest rates may be invalid in these WMUs. For this reason, the PGC does not use PASAK estimates to track deer population trends in these WMUs.

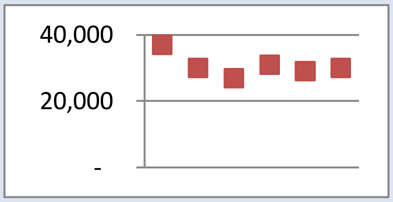
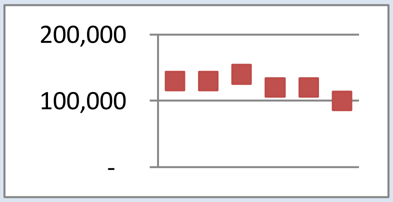
3. PASAK Deer Population Estimates, 2003-09

Pre-hunt PASAK point estimates, lower and upper limits of the 90% confidence interval, coefficients of variation (CVs), population trend assessments, and population points estimates, Pennsylvania 2003 to 2009. Trends and graphs reflect 6 year trends for management. 2003 estimates provided for information only.

Year	WMU	90% Confidence Interval Lower Limit	Pre-hunt Point Estimate	90% Confidence Interval Upper Limit	CV	Population Trend 2004-09	Graph of Deer Population Point Estimates 2004-09
2003	1A	69,695	89,758	122,849	19%		
2004	1A	55,550	71,772	98,022	18%		
2005	1A	62,666	81,482	113,002	19%		
2006	1A	70,762	94,131	130,603	20%		
2007	1A	48,971	63,864	89,154	19%		
2008	1A	52,924	68,861	93,300	18%		
2009	1A	55,629	73,798	105,520	20%	Stable	
2003	1B	66,032	88,280	134,795	23%		
2004	1B	49,279	66,685	99,510	23%		
2005	1B	61,156	84,078	126,424	23%		
2006	1B	69,599	94,054	141,785	23%		
2007	1B	60,206	82,345	123,287	23%		
2008	1B	72,817	97,872	145,468	22%		
2009	1B	52,144	71,504	105,984	24%	Stable	
2003	2A	78,321	99,750	133,524	17%		
2004	2A	58,029	73,712	99,039	17%		
2005	2A	75,098	96,069	128,713	17%		
2006	2A	77,119	99,017	137,151	18%		
2007	2A	57,916	75,950	104,811	18%		
2008	2A	60,972	78,309	106,998	17%		
2009	2A	56,604	72,970	98,387	17%	Stable	
2003	2C	134,036	175,729	251,724	20%		
2004	2C	105,027	138,462	198,380	20%		
2005	2C	92,386	125,302	180,868	21%		
2006	2C	109,949	145,410	205,841	21%		
2007	2C	112,775	150,246	216,372	21%		
2008	2C	99,375	133,998	197,750	21%		
2009	2C	78,065	104,698	153,798	22%	Stable	
2003	2D	111,445	130,855	159,939	11%		
2004	2D	87,796	104,016	125,397	11%		
2005	2D	88,578	104,586	123,580	10%		
2006	2D	110,529	131,469	156,296	10%		
2007	2D	84,938	100,893	120,719	11%		
2008	2D	92,249	108,301	130,157	11%		
2009	2D	84,542	101,455	121,185	11%	Stable	

Year	WMU	90% Confidence Interval Lower Limit	Pre-hunt Point Estimate	90% Confidence Interval Upper Limit	CV	Population Trend 2004-09	Graph of Deer Population Estimates 2004-09
2003	2E	56,125	69,923	89,126	14%		
2004	2E	37,893	47,431	60,838	15%		
2005	2E	45,937	56,949	73,877	15%		
2006	2E	50,195	62,108	78,913	14%		
2007	2E	33,222	41,687	54,058	15%		
2008	2E	42,750	53,341	68,029	14%		
2009	2E	35,198	43,859	57,883	16%	Stable	
2003	2F	95,983	119,269	155,497	15%		
2004	2F	69,021	85,839	113,131	16%		
2005	2F	61,018	77,660	104,228	16%		
2006	2F	80,855	101,797	135,703	16%		
2007	2F	54,605	69,408	94,260	17%		
2008	2F	70,775	89,561	117,750	16%		
2009	2F	51,583	64,850	88,237	17%	Stable	
2003	2G	75,200	103,240	162,435	24%		
2004	2G	60,437	82,580	133,600	26%		
2005	2G	45,409	64,457	102,285	25%		
2006	2G	78,921	111,534	194,119	31%		
2007	2G	47,123	67,202	111,032	28%		
2008	2G	68,575	97,026	166,165	29%		
2009	2G	42,058	58,654	96,695	27%	Stable	
2003	3A	39,189	47,173	58,713	13%		
2004	3A	38,657	46,852	58,421	13%		
2005	3A	36,215	45,168	57,885	14%		
2006	3A	42,461	51,146	63,669	13%		
2007	3A	34,215	42,718	54,043	14%		
2008	3A	30,169	37,198	46,711	13%		
2009	3A	30,183	37,457	47,384	14%	Stable	
2003	3B	57,663	68,630	82,868	11%		
2004	3B	56,464	68,321	83,771	12%		
2005	3B	55,907	66,885	82,630	12%		
2006	3B	58,670	69,898	86,198	12%		
2007	3B	56,444	69,521	86,419	13%		
2008	3B	42,199	50,662	62,061	12%		
2009	3B	45,641	55,176	68,491	13%	Stable	
2003	3C	66,921	87,769	121,706	19%		
2004	3C	66,084	86,500	120,926	20%		
2005	3C	53,555	71,046	101,326	20%		
2006	3C	74,070	98,926	140,776	20%		
2007	3C	55,845	72,001	102,767	19%		
2008	3C	56,259	74,241	104,732	19%		
2009	3C	57,860	75,752	107,578	20%	Stable	

Year	WMU	90% Confidence Interval Lower Limit	Pre-hunt Point Estimate	90% Confidence Interval Upper Limit	CV	Population Trend 2004-09	Graph of Deer Population Estimates 2004-09
2003	3D	44,259	56,721	76,828	17%		
2004	3D	40,387	52,019	70,680	18%		
2005	3D	36,579	48,296	68,359	19%		
2006	3D	45,218	59,047	82,400	18%		
2007	3D	34,559	45,760	63,041	19%		
2008	3D	34,703	45,621	63,608	19%		
2009	3D	23,096	30,792	43,074	20%	Stable	
2003	4A	52,241	64,185	80,000	13%		
2004	4A	34,869	42,485	53,339	13%		
2005	4A	28,692	36,154	46,361	15%		
2006	4A	45,371	54,823	68,213	12%		
2007	4A	43,289	54,800	70,698	15%		
2008	4A	27,329	33,760	42,007	13%		
2009	4A	25,554	31,318	40,336	14%	Stable	
2003	4B	43,382	50,284	60,360	10%		
2004	4B	40,190	47,777	57,678	11%		
2005	4B	31,281	37,405	45,991	12%		
2006	4B	47,092	56,145	68,697	12%		
2007	4B	31,289	38,084	47,722	13%		
2008	4B	35,546	44,472	57,633	15%		
2009	4B	40,002	49,650	63,168	14%	Stable	
2003	4C	44,991	57,224	76,448	17%		
2004	4C	40,437	52,237	71,389	18%		
2005	4C	38,729	50,238	69,053	18%		
2006	4C	43,355	55,880	77,539	18%		
2007	4C	33,486	43,968	59,588	18%		
2008	4C	33,148	42,515	59,685	18%		
2009	4C	30,099	39,095	54,625	19%	Stable	
2003	4D	64,431	75,209	89,734	10%		
2004	4D	46,233	54,508	64,768	10%		
2005	4D	45,676	55,385	69,458	13%		
2006	4D	59,112	69,902	84,053	11%		
2007	4D	41,582	49,169	59,958	11%		
2008	4D	50,049	59,655	72,954	11%		
2009	4D	36,350	43,982	53,944	12%	Stable	
2003	4E	58,750	74,147	96,459	15%		
2004	4E	44,549	55,684	75,079	16%		
2005	4E	56,933	72,971	99,955	18%		
2006	4E	48,270	61,983	81,987	16%		
2007	4E	42,971	55,555	74,672	17%		
2008	4E	44,417	56,175	75,161	16%		
2009	4E	41,778	52,840	70,787	16%	Stable	

Year	WMU	90% Confidence Interval Lower Limit	Pre-hunt Point Estimate	90% Confidence Interval Upper Limit	CV	Population Trend 2004-09	Graph of Deer Population Estimates 2004-09
2003	5A	28,433	39,564	60,599	25%		
2004	5A	26,961	37,252	58,080	25%		
2005	5A	21,319	30,340	46,905	25%		
2006	5A	19,009	26,555	40,377	25%		
2007	5A	20,567	31,290	52,449	30%		
2008	5A	21,068	29,274	44,772	24%		
2009	5A	21,262	29,739	44,838	24%	Stable	
2003	5B	92,275	137,920	237,678	32%		
2004	5B	87,646	129,165	222,274	30%		
2005	5B	85,699	126,342	219,915	32%		
2006	5B	89,790	135,600	244,779	33%		
2007	5B	77,967	115,452	197,294	30%		
2008	5B	79,125	122,279	219,898	33%		
2009	5B	68,191	101,060	180,786	34%	Stable	

4. Deer Population Estimates & Individual Observations: A Closer Look at WMU 2G

Often, deer population estimates and deer sightings serve as the benchmarks upon which deer program credibility is judged.

There is a long history of debate over deer numbers in state deer programs. Pennsylvania has witnessed deer number debates for decades. And, it is likely that PASAK population estimates will generate a new round of debate regarding deer numbers in Pennsylvania.

WMU 2G in northcentral Pennsylvania is often the focus of deer management controversy. Antlered harvests and antlerless hunting opportunities there have declined substantially. At the same time, some have suggested deer numbers are down to 20,000-36,000 deer in this WMU.

One of the most direct ways to estimate wildlife populations is to capture and mark animals and then determine how many were harvested. Because of ongoing field studies in WMU 2G, the PGC can estimate deer populations using harvest rates from marked deer. These harvest rates can then be combined with harvest estimates to calculate the population (See Example 3, Step 2 on page 16 for an example). This is the same method used to estimate bear populations in Pennsylvania. Harvest rate estimates from completed research studies are used for 2007 and 2008.

Deer population estimates using deer harvests and harvest rates from marked deer in 2007 and 2008 are around 70,000 deer (Table 2). These estimates are double or triple the number of deer proposed by some and, as a result, not likely to stop debates over deer numbers. However, opposition to these figures does not discredit the time-proven science used to develop these estimates that are based on the experience of thousands of hunters and hundreds of individually marked deer in WMU 2G. It simply marks a disagreement, not wrongdoing.

Given that deer are not evenly distributed across a WMU, the scale at which one looks at deer populations – and the resulting inferences and perceptions – will continue to complicate deer population discussions. Whereas hunters and the public look at local areas, biologists have to look at the entire WMU.

WMU results represent a broad sampling from deer and hunters within the area. For this reason, judging WMU results based on personal experience is not appropriate. Recognition of these differences and how unrelated WMU results may be to personal observations must occur if the deer number debate is to ever diminish.

Table 2. Population estimates based on marked deer, Pennsylvania WMU 2G, 2007 and 2008.

Year	Population Estimate
2007	70,849
2008	70,809

5. Description of the PASAK Model

Although Pennsylvania's deer management goals are no longer defined by deer abundance, monitoring deer population trends is important to the deer management program. Deer population trends are a consideration when making antlerless license allocation recommendations needed to achieve management goals.

In 19 of 22 WMUs, deer population trend monitoring is based on the PASAK model. The 3 WMUs around Pittsburgh and Philadelphia (WMUs 2B, 5C, and 5D) are more developed than other WMUs. Consequently, increased uncertainty regarding assumptions in the PASAK model prevents its use in these developed WMUs.

The PGC uses the sex-age-kill (SAK) method of population reconstruction (Eberhardt 1960, Creed et al. 1984, Skalski and Millspaugh 2002) with modifications for Pennsylvania's antler restrictions. Population trend estimation relies on the PGC's strongest data sets; data from large-scale field studies, harvest estimates, and sex and age composition of the harvest. Harvest estimates and sex and age composition of harvest are available for each WMU. Data from field studies, including harvest and survival rates, are limited to a few WMUs. Population estimates begin with mature males (males 1.5 years of age and older) and progress to mature females and juveniles (<1 year old).

Procedures

The antlered harvest, $\widehat{K}_{Antlered}$ for each WMU, is estimated using Chapman's (1951) modified Lincoln-Petersen estimator,

$$\widehat{K}_{Antlered} = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1$$

where n_1 is the number of antlered deer checked by deer aging teams in the field, n_2 is the number of antlered deer reported via report cards by hunters, and m_2 is the number of antlered deer checked by deer aging teams and reported via report cards by hunters.

Example 2. Estimating Antlered Harvest

400 antlered deer checked by PGC personnel
1,000 antlered deer reported by hunters using report cards or the Internet
160 of the 400 antlered deer checked by PGC personnel were reported by hunters using report cards or the Internet

$$\widehat{K}_{Antlered} = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1$$

$$\widehat{K}_{Antlered} = \frac{(400 + 1)(1{,}000 + 1)}{(160 + 1)} - 1$$

$$\widehat{K}_{Antlered} = 2{,}492 \ antlered\ deer\ harvested$$

Antlered harvest estimates and age structure are used to estimate the number of harvested adult males (≥2.5 years-old) as,

$$\widehat{K}_{Adult\ Males} = \widehat{K}_{Antlered}(\hat{\rho}_{Age(Adult\ Males)})$$

where $\widehat{K}_{Adult\ Male}$ is an estimate of the number of harvested adult males, $\widehat{K}_{Antlered}$ is the estimated antlered harvest, and $\hat{\rho}_{Age(Adult\ Male)}$ is the proportion of adult males in the antlered harvest.

The adult male population is estimated as,

$$\widehat{N}_{Adult\ Males} = \frac{\widehat{K}_{Adult\ Males}}{\widehat{H}_{Adult\ Males}}$$

where $\widehat{N}_{Adult\ Males}$ is the estimated population of adult males and $\widehat{H}_{Adult\ Males}$ is the harvest rate for adult males.

Example 3. Estimating Adult Male Population

Step 1. Estimate adult male harvest

2,492 antlered deer harvested
50% of antlered deer in harvest were adult males

$$\widehat{K}_{Adult\ Males} = \widehat{K}_{Antlered}(\hat{\rho}_{Age(Adult\ Males)})$$

$$\widehat{K}_{Adult\ Males} = 2{,}492(0.50)$$

$$\widehat{K}_{Adult\ Males} = 1{,}246\ adult\ males\ harvested$$

Step 2. Estimate adult male population

60% of adult males with radio-collars were harvested by hunters

$$\widehat{N}_{Adult\ Males} = \frac{\widehat{K}_{Adult\ Males}}{\widehat{H}_{Adult\ Males}}$$

$$\widehat{N}_{Adult\ Males} = \frac{1{,}246}{0.60}$$

$$\widehat{N}_{Adult\ Males} = 2{,}077\ adult\ males\ in\ population$$

Once the adult male population is estimated, the next step is to estimate the subadult (1.5 year-old) male population. Antlered harvest estimates and age structure are used to estimate the number of harvested subadult males as,

$$\widehat{K}_{Subadult\ Males} = \widehat{K}_{Antlered}(\hat{\rho}_{Age(Subadult\ Males)})$$

where $\widehat{K}_{Subadult\ Male}$ is an estimate of the number of harvested subadult males, $\widehat{K}_{Antlered}$ is the estimated antlered harvest, and $\hat{\rho}_{Age(Subadult\ Male)}$ is the proportion of subadult males in the antlered harvest.

The subadult male population is estimated as,

$$\widehat{N}_{Subadult\ Males} = \frac{\widehat{K}_{Subadult\ Males}}{\widehat{H}_{Subadult\ Males}}$$

where $\widehat{N}_{Subadult\ Males}$ is the estimated population of subadult males and $\widehat{H}_{Subadult\ Males}$ is the harvest rate for subadult males.

Example 4. Estimating Subadult Male Population

Step 1. Estimate subadult male harvest

2,492 antlered deer harvested
50% of antlered deer in harvest were subadult males

$$\widehat{K}_{Subadult\ Males} = \widehat{K}_{Antlered}(\hat{\rho}_{Age(Subadult\ Males)})$$

$$\widehat{K}_{Subadult\ Males} = 2{,}492(0.50)$$

$$\widehat{K}_{Subadult\ Males} = 1{,}246\ subadult\ males\ harvested$$

Step 2. Estimate subadult male population

30% of subadult males with radio-collars were harvested by hunters

$$\widehat{N}_{Subadult\ Males} = \frac{\widehat{K}_{Subadult\ Males}}{\widehat{H}_{Subadult\ Males}}$$

$$\widehat{N}_{Subadult\ Males} = \frac{1{,}246}{0.30}$$

$$\widehat{N}_{Subadult\ Males} = 4{,}153\ subadult\ males\ in\ population$$

With current year population estimates of subadult and adult males, the population of mature males is estimated as,

$$\widehat{N}_{Mature\ Males} = \widehat{N}_{Subadult\ Males} + \widehat{N}_{Adult\ Males}\ .$$

Example 5. Estimating Mature Male Population

4,153 subadult males from Example 4
2,077 adult males from Example 3

$$\widehat{N}_{Mature\ Males} = \widehat{N}_{Subadult\ Males} + \widehat{N}_{Adult\ Males}$$

$$\widehat{N}_{Mature\ Males} = 4{,}153 + 2{,}077$$

$$\widehat{N}_{Mature\ Males} = 6{,}230\ mature\ males$$

After the mature male population is estimated, the mature female population is estimated. The first step in estimating mature females, is to estimate the mature deer sex ratio. Assuming males and females are recruited into the population in equal numbers at 1.5 years of age, the adult sex ratio can be estimated as,

$$\hat{R}_{F/M} = \frac{\hat{\rho}_{Subadult\ Males}}{\hat{\rho}_{Subadult\ Females}}$$

where $\hat{R}_{F/M}$ is the ratio of mature females to mature males and $\hat{\rho}_{Subadult\ Males}$ is estimated as,

$$\hat{\rho}_{Subadult\ Males} = \frac{\hat{N}_{Subadult\ Males}}{\hat{N}_{Mature\ Males}}$$

and $\hat{\rho}_{Subadult\ Females}$ is estimated as,

$$\hat{\rho}_{Subadult\ Females} = \frac{k_{Subadult\ Females}}{k_{Subadult\ Females} + k_{Adult\ Females}}$$

where $k_{Subadult\ Females}$ is the number of subadult females aged in the harvest and $k_{Adult\ Females}$ is the number of adult females aged in the harvest.

The mature female population, $\hat{N}_{Mature\ Females}$, is then estimated as,

$$\hat{N}_{Mature\ Females} = \hat{N}_{Mature\ Males}\hat{R}_{F/M}\ .$$

Example 6. Estimating Mature Female Population

Step 1. Estimate proportion of subadult males in the mature male population

4,153 subadult males from Example 4
6,230 mature males from Example 5

$$\hat{\rho}_{Subadult\ Males} = \frac{\hat{N}_{Subadult\ Males}}{\hat{N}_{Mature\ Males}}$$

$$\hat{\rho}_{Subadult\ Males} = \frac{4{,}153}{6{,}230}$$

$$\hat{\rho}_{Subadult\ Males} = 0.67$$

Step 2. Estimate proportion of subadult females in the mature female population

200 subadult females aged by deer agers
400 adult female aged by deer agers

$$\hat{\rho}_{Subadult\ Females} = \frac{k_{Subadult\ Females}}{k_{Subadult\ Females} + k_{Adult\ Females}}$$

$$\hat{\rho}_{Subadult\ Females} = \frac{200}{200 + 400}$$

$$\hat{\rho}_{Subadult\ Females} = 0.33$$

Step 3. Estimate mature female to mature male ratio

$$\hat{R}_{F/M} = \frac{\hat{\rho}_{Subadult\ Males}}{\hat{\rho}_{Subadult\ Females}}$$

$$\hat{R}_{F/M} = \frac{0.67}{0.33}$$

$$\hat{R}_{F/M} = 2\ mature\ females\ to\ 1\ mature\ male$$

Step 4. Estimate mature female population

$$\hat{N}_{Mature\ Females} = \hat{N}_{Mature\ Males}\hat{R}_{F/M}$$

$$\hat{N}_{Mature\ Females} = (6{,}230)(2)$$

$$\hat{N}_{Mature\ Females} = 12{,}460\ mature\ females$$

Once the adult female population is estimated, juveniles (<1 year old) are estimated as:

$$\hat{N}_{Juveniles} = \hat{N}_{Mature\ Females}\hat{R}_{J/F}$$

where $\hat{R}_{J/F}$ is the ratio of juveniles to mature females in the antlerless harvest and is estimated as:

$$\hat{R}_{J/F} = \frac{k_{Juveniles}}{k_{Mature\ Females}}$$

where $k_{Juveniles}$ is the number of juveniles aged in the harvest and $k_{Mature\ Females}$ is the number of mature females aged in the harvest.

Example 7. Estimating Juvenile Population

Step 1. Estimate juvenile to mature female ratio in harvest

400 juveniles were aged by deer aging teams
600 mature females were aged by deer aging teams from Example 6, Step 2

$$\hat{R}_{J/F} = \frac{k_{Juveniles}}{k_{Mature\ Females}}$$

$$\hat{R}_{J/F} = \frac{400}{600}$$

$$\hat{R}_{J/F} = 0.67$$

Step 2. Estimate juvenile population

12,460 mature females from Example 6

$$\hat{N}_{Juveniles} = \hat{N}_{Mature\ Females}\hat{R}_{J/F}$$

$$\hat{N}_{Juveniles} = 12{,}460(0.67)$$

$$\hat{N}_{Juveniles} = 8{,}348\ juveniles$$

The total population then is estimated as:

$$\hat{N}_{Total} = \hat{N}_{Mature\ Males} + \hat{N}_{Mature\ Females} + \hat{N}_{Juveniles}$$

where $\hat{N}_{Total}$ is the estimated deer population.

Example 8. Estimating Total Population

6,230 mature males from Example 5
12,460 mature females from Example 6
8,348 juveniles from Example 7

$$\hat{N}_{Total} = \hat{N}_{Mature\ Males} + \hat{N}_{Mature\ Females} + \hat{N}_{Juveniles}$$

$$\hat{N}_{Total} = 6{,}230 + 12{,}460 + 8{,}348$$

$$\hat{N}_{Total} = 27{,}038\ deer\ in\ population$$

Precision of the PASAK model was quantified using a Monte Carlo parametric bootstrapping method (Efron 1979) similar to Millspaugh et al. (2007). We conducted 1,000 Monte Carlo bootstraps of the empirical data to generate 1,000 population estimates from a random selection of the data taken with replacement. A fundamental assumption of the parametric bootstrap is that each parameter is assumed to have some underlying distribution with a specific mean and variance (Millspaugh et al. 2007). Because all PASAK model parameters were constrained between 0 and 1, we conducted the bootstrap using either a binomial distribution, $b(n,p)$, or a beta distribution, $beta(\mu, \delta^2)$, based on empirical data collected by the PGC. Precision of population estimates was the standard deviation of the replicate simulation estimates of N and 90% confidence intervals were estimated from the 5th and 95th percentiles of simulation estimates of N.

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For more information on the Deer Management Program, please visit the Game Commission's website,

www.pgc.state.pa.us

and click on the "White-tailed Deer" button.