A SPATIALLY EXPLICIT MODEL OF THE WHITE-TAILED DEER POPULATION IN DELAWARE

by

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POPULATION IN DELAWARE

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ABSTRACT

White-tailed deer (*Odocoileus virginianus*) population models are used by many states to predict population levels and aid in making management decisions. Delaware did not have a deer population model, so I developed a model and used it to investigate the implications of changes to the harvest. I used survival rates, reproductive rates, harvest data, a population estimate, and spotlight counts to construct the model. The changes to the harvest regime that I considered were permitting Sunday hunting during the opening weekend of the November firearm season, adding 1 week to the November shotgun season, termination of the severe deer damage permits, closing the October antlerless shotgun season, closing the shotgun season in January, closing the muzzleloader season in January, and closing both shotgun and muzzleloader seasons in January. The model began in February 2006 after the conclusion of the 2005-2006 hunting season and I ran the scenarios until August 2014. Without changing the harvest regime, my model predicted the state population to decrease 28% by the fall of 2014. Allowing Sunday hunting during the opening weekend of the main firearm season and adding an additional week onto the main firearm season caused the population to decline at a greater rate by 2014. Terminating the severe deer damage program did not impact the 2014 predicted deer population compared to the scenario without changing the harvest regimes. Closing the October antlerless season and the January shotgun season caused a 23% increase to the 2014 predicted population, in both scenarios. Compared to scenario without changing the harvest regimes, the deer population was 11% greater in 2014 with the January muzzleloader season closed and 37% greater in 2014 with both January shotgun and muzzleloader seasons closed. The model predicted that the different

deer management zones have very different population levels and harvest rates. To date, the harvest regimes in Delaware have only been changed at the state level but future changes to the harvest regimes should occur at the zone level. Several options are available for managers to increase or decrease the deer population by 2014. Managers can further reduce the deer population by allowing Sunday hunting during the opening weekend of the main firearm season and/or adding an additional week onto the main shotgun season. If managers decide to slow or stop the population decline, then closing the October antlerless season and/or the late January seasons are the best methods. Terminating the severe deer damage assistance program is not an effective method to slow or stop the declining trend, because removing the deer harvested under the program only caused a 4% increase to the 2014 population. Depending on the desired 2014 population level, managers can adjust the harvest regimes accordingly to meet their population goal.

Chapter 1

INTRODUCTION

Modeling is the process of representing a population through mathematical equations (Akçakaya 2004). Models give insight into how animal populations work, predict future population trends, and help wildlife managers make decisions (Akçakaya 2004). Population modeling is an important tool for wildlife management because models allow managers to quickly and easily test management strategies without conducting field experiments (McCarthy 2004). The effectiveness of the different management strategies can be assessed using a model and the strategy that achieves the management goals can be implemented. After implementing the scenario, the manager can then analyze the data to see if the management goals were achieved and if any discrepancies occurred with the model (McCarthy 2004).

Sezen et al. (2004) modeled the effects of different hunting regimes on a Turkish mouflon (*Ovis gmelinii anatolica*) population to determine the optimal harvest rate with the least negative impact on the species. Another example, Lopez (2004) modeled the effect of different land development scenarios on the Florida key deer (*Odocoileus virginianus clavium*) population. These types of models are used as management tools to evaluate proposed changes to current management practices.

White-tailed deer (*Odocoileus virginianus*) population models are a commonly used management tool. Models have been used by many states to generate population estimates and predict future populations, but most models are not used to model specific management scenarios before implementation. Maryland and Pennsylvania use models to estimate deer populations, but neither state uses their model to predict future populations when harvest regimes are modified (Maryland Department of Natural Resources 1998, Pennsylvania Game Commission Bureau of Wildlife Management 2002). The models used by these states are not used as tools to justify changes in harvest regimes, but as a way of measuring the effect on the population, after harvest regimes have been changed.

Missouri uses a model that simulates the population sizes for each county based on the number of mortalities (L.P. Hansen, Missouri Department of Conservation, personal communication). The Missouri model was used when implementing antler restrictions in parts of the state to determine the required mortality rates to achieve management goals (L.P. Hansen, Missouri Department of Conservation, personal communication). However, the Missouri model is not based on a population estimate and the model can not predict the number of harvested deer required to reduce or manage a population at a desired level.

Currently the Delaware Division of Fish and Wildlife (hereafter Delaware Fish and Wildlife) does not have a white-tailed deer population model to aid in making management decisions. For example, wildlife managers in Delaware were forced, by politics, to add a handgun season to the 2005-2006 white-tailed deer hunting season. The managers had no way to determine what effect if any the new season would have on the deer population. Using a model, the managers could have determined the appropriate season length and bag limits to meet their management goals. A model can provide scientific data for managers to justify any changes of harvest regimes. My objectives were to develop a spatially explicit population model of the white-tailed deer population in Delaware and then to use that model to determine the effect of several changes to the harvest regimes on the white-tailed deer population in Delaware.

Chapter 2

STUDY AREA

I developed my model for the state of Delaware (5193.35 km^2) which is located in the mid-Atlantic region of the United States. Delaware is bordered by Pennsylvania to the north and Maryland to the west and south. To the east, Delaware is bordered by the Delaware River, Delaware Bay, and Atlantic Ocean

In Delaware (1971-2000), the average annual high and low temperature in January was 5.6˚C and -5.1˚C, respectively, and the average annual high and low temperature in July was 26.7˚C and 22.8˚C, respectively (National Oceanic and Atmospheric Administration 2008). The average annual precipitation was 113.9 cm (National Oceanic and Atmospheric Administration 2008).

Delaware has 3 counties and 17 deer management zones (Figure 2.1). The topography north of the Chesapeake and Delaware Canal, the southern boundary of zone 1, is rolling hills. Most of the landscape north of the Chesapeake and Delaware Canal was developed with the cities of Wilmington, Newark, New Castle, and the surrounding suburbs. South of the Chesapeake and Delaware Canal, the topography is flat and the landscape was dominated by agriculture fields and small woodlots. The primary agriculture crops of Delaware were chickens (*Gallus domesticus*), corn (*Zea mays*), soybeans (*Glycine maxand*), and wheat (*Triticum aestivum*). Two large urban and suburban areas occurred south of the Chesapeake and Delaware Canal, Dover and the beach resorts of Rehoboth, Dewey, and Bethany. Most (77%) of Delaware was considered deer habitat (Table 2.1). I defined deer habitat as agriculture, rangeland, forest, and wetlands.

The white-tailed deer hunting seasons in Delaware occurred 1 September to 31 January in 2005-2007. The archery season began 1 September and ended 31 January. Delaware had 2 muzzleloader seasons. The 1st muzzleloader season began on the 2nd Friday in October and lasted 9 days until the following Saturday, excluding Sunday. The 2nd muzzleloader season began the 2nd to last Saturday in January and lasted 8 days until the following Saturday, excluding Sunday. The handgun season in Delaware began the 1st Saturday in January and lasted 8 days until the following Saturday, excluding Sunday (Delaware Division of Fish and Wildlife 2007). Delaware had 4 shotgun seasons. The 1st shotgun season was 7 antlerless harvest days, in October. The October shotgun season consisted of the 1st Friday and Saturday, 2nd to last Monday, Friday and Saturday, and the last Monday and Friday. The main shotgun season began the 2nd Friday in November and lasted 9 days until the following Saturday, excluding Sunday. The 3rd shotgun season was antlerless harvest only and began the 2nd Saturday in December and lasted 8 days until the following Saturday, excluding Sunday. The last shotgun season began the 3rd Saturday in January and lasted 8 days until the following Saturday, excluding Sunday (Delaware Division of Fish and Wildlife 2007).

Hunters were permitted to harvest 2 does and 2 antlerless deer with the purchase of a license. Additional antlerless tags were available for purchase in unlimited quantities. Two additional tags were available for purchase if a hunter wanted to harvest a buck. The hunter’s choice tag allowed the hunter to harvest any deer (buck or doe).

The quality buck tag allowed the hunter to harvest a buck with an inside antler spread of 38.1 cm or more (Delaware Division of Fish and Wildlife 2007).

Table 2.1 The 2002 land use land cover data (Delaware Spatial Data Implementation Team (I-Team), EarthData International of Maryland, LLC 2003) in km^2 for the 17 white-tailed deer management zones in the State of Delaware and the percentage of habitat relative to the total area of the zone shown in parentheses. Deer habitat was defined as agriculture, rangeland, forest, and wetlands.

Area	Developed	Agriculture	Rangeland	Forest	Open Water	Wetlands	Beach/other	Total	Deer Habitat
Zone 1	383 (61%)	61 (10%)	13 (2%)	111 (18%)	17 (3%)	30 (5%)	11 (2%)	626	215 (34%)
Zone 2	60 (19%)	162 (52%)	3 (1%)	35 (12%)	4 (1%)	42 (32%)	4 (1%)	311	243 (78%)
Zone 3	22 (9%)	95 (38%)	1 (1%)	26 (11%)	16 (6%)	86 (35%)	2 (1%)	248	208 (84%)
Zone 4	47 (19%)	124 (50%)	2 (1%)	27 (11%)	2 (1%)	41 (17%)	2 (1%)	246	194 (79%)
Zone 5	32 (10%)	119 (38%)	2 (0%)	16 (5%)	24 (8%)	118 (38%)	2 (1%)	312	254 (81%)
Zone 6	42 (15%)	146 (51%)	3 (1%)	30 (10%)	1 (0%)	64 (22%)	1 (0%)	288	243 (84%)
Zone 7	15 (6%)	142 (57%)	3 (1%)	27 (11%)	0 (0%)	60 (24%)	0 (0%)	248	233 (94%)
Zone 8	63 (17%)	198 (53%)	6 (2%)	53 (14%)	6 (2%)	42 (11%)	3 (1%)	372	299 (80%)
Zone 9	32 (9%)	120 (35%)	3 (1%)	32 (9%)	18 (5%)	127 (38%)	6 (2%)	339	283 (83%)
Zone 10	20 (9%)	134 (62%)	6 (3%)	22 (10%)	1 (0%)	32 (15%)	0 (0%)	215	194 (90%)
Zone 11	28 (9%)	138 (43%)	19 (6%)	64 (20%)	2 (1%)	64 (20%)	2 (1%)	318	285 (90%)
Zone 12	42 (15%)	125 (43%)	11 (4%)	64 (22%)	4 (1%)	41 (14%)	2 (1%)	288	241 (83%)
Zone 13	31 (13%)	116 (50%)	6 (3%)	40 (17%)	5 (2%)	35 (15%)	0 (0%)	234	198 (84%)
Zone 14	15 (7%)	104 (50%)	9 (4%)	51 (25%)	2 (1%)	25 (12%)	1 (1%)	207	189 (91%)
Zone 15	70 (18%)	109 (28%)	7 (2%)	90 (23%)	76 (19%)	39 (10%)	5 (1%)	397	246 (62%)
Zone 16	14 (5%)	139 (48%)	7 (2%)	41 (14%)	1 (0%)	89 (30%)	1 (0%)	291	276 (95%)
Zone 17	53 (21%)	95 (38%)	4 (2%)	38 (15%)	10 (8%)	40 (16%)	3 (1%)	252	177 (70%)
Total	969 (19%)	2127 (41%)	107 (2%)	769 (15%)	200 (4%)	974 (19%)	48 (1%)	5193	3977 (77%)

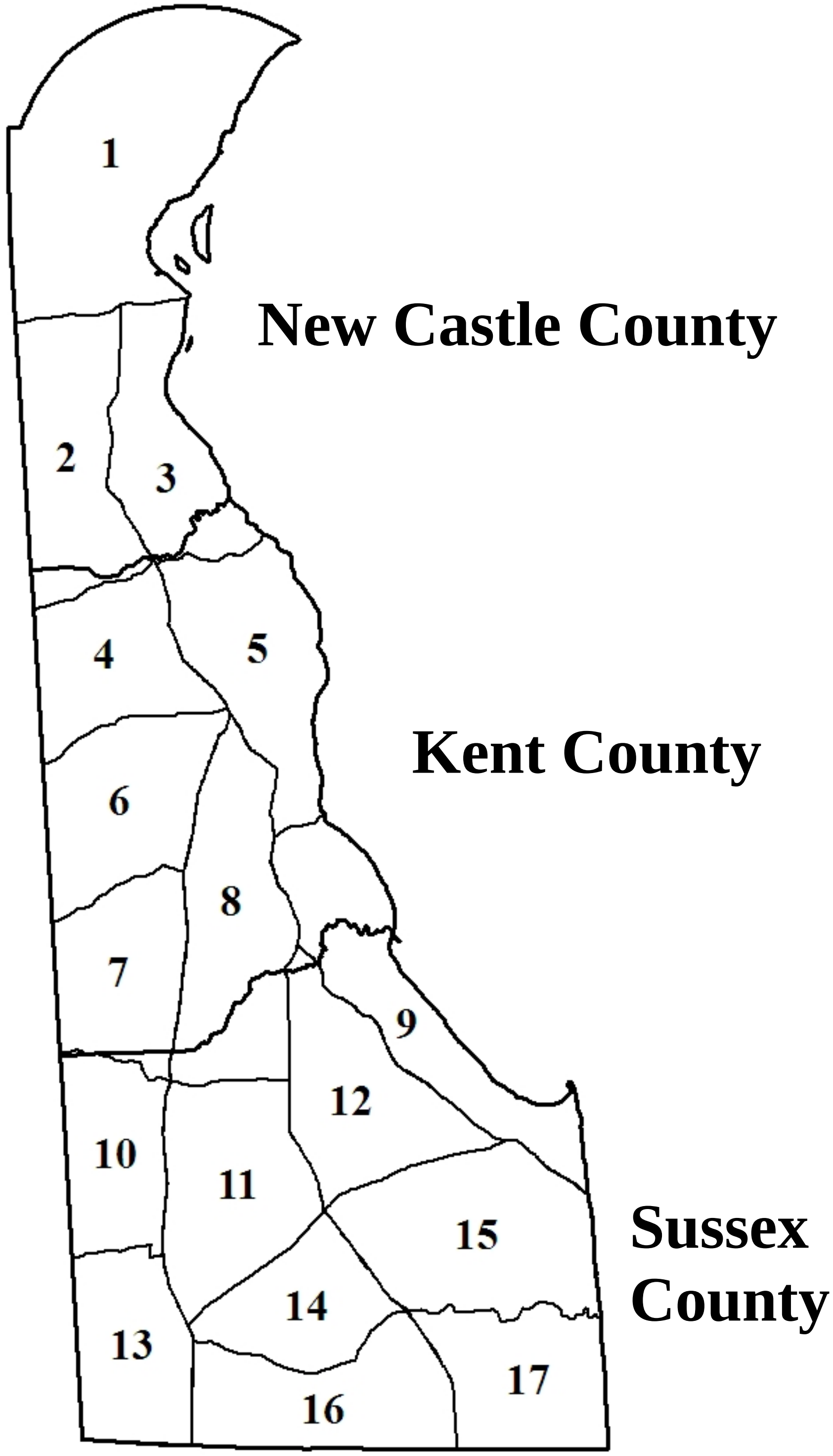

Figure 2.1 The state of Delaware and the location of the 17 deer management zones used to model the white-tailed deer population, 2005-2014. The 3 county boundaries are shown in the bolder lines.

Chapter 3

METHODS

I used the modeling program RAMAS Metapop (Akçakaya and Root 2002) to construct a spatially explicit population model of white-tailed deer in Delaware. I used the model to test changes to the current harvest regime on the trajectory of the population. I considered 8 scenarios:

1. No change to the current harvest regime
2. Permitting Sunday hunting during the opening weekend of the November firearm season
3. Adding 1 week to the November shotgun season
4. Termination of the severe deer damage permits
5. Closing the October antlerless shotgun season
6. Closing the shotgun season in January
7. Closing the muzzleloader season in January
8. Closing both shotgun and muzzleloader seasons in January

I modeled each management zone in Delaware as its own population, and therefore investigated the implications of changes to the harvest regime at the scale of deer harvest management for the state. The model began in February 2006 after the conclusion of the 2005-2006 hunting season and I ran each scenario until August 2014.

3.1 Stage Matrix

I developed an age-structured, sex-specific model of the 17 deer management zones. I modeled fecundity and survival rates for both sexes. I included 2 age classes, fawns (0-1 year) and adults (1 ≥ year), because the Delaware harvest data was provided in these 2 age classes and the fecundity rates differed between the 2 age classes (Table 3.1). One form of variability was incorporated using the standard deviation matrix to account for different reproductive success rates and different reported survival rates (Table 3.1).

3.2 Survival

The survival rates used for the stage matrix came from the mean survival rates I calculated from studies on cause specific mortality of white-tailed deer (Table 3.2). The survival rates I calculated did not include mortality from legal hunting, mortality from hunting related wounding, poaching, and vehicle collisions. I modeled legal hunting, mortality from hunting related wounding, and poaching separately. I used the Auto Insurance Industry estimate of 0.06 annual deer mortality in Delaware for mortality from automobiles collisions (M. Miles, State Farm Insurance, unpublished data, 2008.) The annual deer mortality from the auto industry estimate was similar to the mean vehicle mortalities reported in the literature (Table 3.3). I subtracted 0.06 from the mean survival rates I calculated from the literature (Table 3.2) to account for annual vehicle mortality in the model.

I included mortality from: natural and unknown causes, disease, drowning, starvation, trains, and predation from dogs. I did not include mortality from coyote

(*Canis latrans*) predation. Delaware lacks a coyote population large enough to effect white-tailed deer survival rates, because over the last 3 years (2006-2008) Delaware had 5 confirmed coyote sightings (personal communication, Joe Rogerson Delaware Fish and Wildlife). Gray wolf (*Canis lupis*) and American black bear (*Ursus americanus*) predation were excluded because Delaware lacks these species.

I did not use the following studies when I calculated the mean survival rates because they did not provide data in the format required by my model. I did not use the Klaver et al. (2008) and DelGiudice et al. (2006) studies because they did not report cause specific mortality. I could not use DeYoung (1989) and Webb et al. (2007) because both studies only sampled mature bucks older than 2.5 years. I did not use fawn survival rates from Saalfeld and Ditchkoff (2007), Carroll and Brown (1977), and Cook et al. (1971) because they did not track fawns for at least 12 weeks or until the start of the hunting seasons. I could not use DelGiudice et al. (2002) because their study did not report the year or cause specific mortality of female white-tailed deer. I did not use the Van Deelen et al. (1997) data because they did not report cause specific mortality per year of the deer in their study. I could not use the fawn data from Etter et al. (2002) because they only reported female fawn survival rates and mortality causes. I did not use DePerno et al. (2000) because they reported coyote predation lumped in with other natural causes.

3.3 Fecundity

I calculated the fecundity values using data collected from female deer harvested in Delaware by hunters and sharp shooters January - April 2006. The deer were taken to a central check station where Delaware Fish and Wildlife staff and volunteers gathered data from the female deer. The does were weighed, jaws were removed for aging, and the fetuses or ovaries were removed for examination. Does were aged using tooth wear and replacement (Severinghaus 1949). The fetuses were sexed and aged according to Hamilton et al. (1985) method with a white-tailed deer fetus scale (Forestry Supply Inc., Jackson, Miss.). If no fetuses were present, the ovaries were removed and examined for corpora lutea of pregnancy or ovulation (Parker and Matson 1995). The mean number of fawns per doe was 0.10 (SD 0.06) and 1.88 (SD 0.04) for the fawn doe and adult doe age classes, respectively.

For both age classes, I divided the number of fawns per doe by 2, which gave the number of male and female fawns at birth. I divided the number of fawns per doe by 2 because the fetus sex ratio from the deer harvested by sharp shooters and hunters in Delaware was 102:97 male to female (i.e., 1:1 ratio). The number of fawns per doe was used as the fecundity values in the stage matrix.

3.4 Population Density

The initial zone populations (Table 3.4) for the model came from a population estimate conducted by Vision Air Research Inc. (hereafter Vision Air) 6-17 December 2005. Delaware Fish and Wildlife contracted Vision Air to conduct a deer population survey using forward-looking infrared (FLIR). One sample plot 3.2 km by 12.9 km was selected within each of the 17 management zones. The sample plots were representative of the percentage of land use land cover in their respective zone based on the 2002 land use land cover data.

Vision Air used a Cessna 206 with a FLIR (PolyTech Kelvin 350 II) attached to the left wing and flew transects 152.4 meters apart within the 17 sample plots (Bernatas 2006). Then number of deer groups and the number of deer in each group were counted for each sample plot. The number of deer observed within the sample plot was divided by the amount of deer habitat in the sample plot, which gave the sample plot density. The sample plot density was multiplied by the total amount of deer habitat in the zone, which gave the number of deer per zone.

3.5 Population Demographics

The FLIR survey provided an estimate of the deer density for each zone, but it did not provide an estimate of the percentages of bucks, does, or fawns in the population. I used spotlight surveys to estimate the percentages of bucks, does and fawns. I wanted to conduct 5 replications of each spotlight count route, before fawns stopped following does, making identification between the 2 difficult. I drove 1 survey route in zones 1, 5, and 6.

My goal was to see at least 50 identifiable deer along the survey route within each zone. Zones 5 and 6 were in rural areas dominated by agriculture, so I conducted the surveys from state, county, and local roads avoiding roads near zone borders. Zone 1 was dominated by commercial and residential development, therefore, I did not use the state, county, and local roads for the surveys, due to the high traffic volume. I used Middle Run, a New Castle County park for the zone 1 survey and drove on park roads and fields for the route. The park was representative of zone 1 because the northern part of the park was located in the FLIR survey sample plot for zone 1.

The surveys began ½ hour after sunset and ended before 2400. Only 1 survey route was driven per night due to the length of time required to complete each route. I repeated each survey 5 times, 5 September-2 October 2007. The night of the 1st survey in each zone I drove until I saw at least 50 identifiable deer. The following 4 replications I drove the same route as the 1st night of the survey. I recorded the number of deer clusters, number of bucks, does, or fawns within each cluster, whether the deer were standing or lying, the distance from the route (meters), and the kilometer along the route where the cluster occurred.

I totaled the number of bucks, does, fawns, and unidentifiable deer for each survey. I divided the number of bucks, does, or fawns by the number of identifiable deer, which gave the percent of bucks, does, and fawns per zone. I calculated the mean percent of bucks, does, and fawns for the 3 zones. I used the mean percent of bucks (19%), does (41%), and fawns (40%) to distribute the FLIR population estimates for each zone (Table 3.5).

3.6 Harvest

The harvest data in Delaware was collected using physical check stations and an automated system via telephone or internet. For the 2005-2006 harvest season, 60% of the deer were checked at physical check stations and 40% were checked using the automated system. When a hunter reported his or her harvest, a harvest number was assigned to each record. Hunter name, address, phone number, hunting license number and type, hide tag number, zone and county where the deer was harvested, season and weapon used, public or private land, public land code (if applicable), date of harvest, type of tag used, check station code, type of deer killed (i.e., antlered buck, adult doe, button buck, fawn doe, or spike buck), and additional comments were collected for each harvest record. I used the harvest data from Delaware to estimate the hunting mortalities in each zone.

The harvest data collected from the check stations and the automated system represents the deer legally harvested and recovered. The harvest data did not contain mortalities from poaching or deer fatalities from hunting related wounding. I used survival and mortality studies on white-tailed deer that reported mortality rates for poaching and fatalities from hunting related wounding. I determined the annual poaching and fatalities from hunting related wounding were 29% of the reported legal harvest (Table 3.6). I corrected the Delaware reported harvest data for poaching and fatalities from hunting related wounding by multiplying the reported harvest by 1.29.

I also used harvest data from Maryland, which did not have physical check stations. All deer were checked using an automated system through the internet or telephone. Maryland collected similar data as Delaware, but Maryland only recorded the type of deer killed as antlered buck, doe, button buck, or spike buck.

I used the average of the 2005-2006 and 2006-2007 Delaware harvest data to estimate harvest rates for my model. Only the 2005-2006 and 2006-2007 harvest data was used because previous years did not provide specific information on the age of the deer and what weapon was used to harvest the deer. I determined the annual harvest rate for each zone and age class by dividing the mean of the Delaware 2005-2006 and 2006-2007 harvest data by the 2005 FLIR population survey. I calculated the 17 zone mean harvest rates for the 4 stages. I used the mean annual harvest rates for the 4 stages to predict the future harvest and changes to the deer population.

3.7 Calibration

While testing the model for accuracy, I found the 2006-2007 and 2007-2008 harvests were overestimated by 20-25%. I calibrated the model to estimate the 2006-2007 and 2007-2008 harvests within 5% of the actual harvest, including poaching and fatalities from hunting related wounding. First I tried reducing the harvest rate and I was able to predict the 2006-2007 harvest within 5% of the actual harvest, but was unable to predict the 2007-2008 harvest within 5% of the actual harvest. Next I tried to reduce only the survival rates in the stage matrix and I could predict the 2007-2008 harvest with in 5% of the actual harvest, but not the 2006-2007 harvest. Finally I reduced the survival rates in the stage matrix and the harvest rates and I was able to estimate both the 2006-2007 and 2007-2008 harvests with 5% of the actual harvest.

3.8 Scenarios

I manipulated the hunting season in Delaware 7 different ways, based on suggestions from Delaware Fish and Wildlife managers. Two manipulations involved adding extra days on to the November shotgun season. In the other 5 scenarios I closed different seasons. I also ran a scenario without changing the harvest regimes to compare the effect of the 7 scenarios with harvest regimes changes. The harvest season manipulations began in the 2009-2010 hunting season and ran through the 2013-2014 harvest season, a period of 5 years. I ran 1000 replications of the 8 scenarios for 5 years to predict the population in August 2014. I evaluated the scenarios by looking at the change in the zone populations from the 2005 FLIR population estimate and the change in the statewide deer harvest. I did not evaluate harvest on a zone by zone basis, because I used the 17 zone mean harvest rate and to date managers have only changed harvest regimes at the state level and not at the zone level.

3.8.1 Permitting Sunday hunting during the opening weekend of the November firearm season

Delaware does not allow Sunday hunting because of tradition and social taboos against Sunday hunting. However, 43 states (National Rifle Association Institute for Legislative Action 2009) allow some form of Sunday hunting, because it gives hunters another day to hunt and may lead to increased harvest rates. I modeled the addition of Sunday hunting during the 1st weekend of the November shotgun season, to evaluate its impact on the overall harvest. I used harvest data from Maryland to model Sunday hunting during the opening weekend of Delaware's November shotgun season.

In 2003 Maryland opened Sunday hunting, on private lands, during the opening weekend of the main firearms season. The main firearm season in Maryland began the 1st Saturday after Thanksgiving and lasted 15 days without Sunday hunting on the second Sunday. Sunday hunting was only allowed in some of the counties on the eastern shore, central, and western part of the state. I used the harvest data from Caroline, Cecil, Dorchester, Kent, Queen Anne's, and Talbot counties in Maryland, because they allowed Sunday hunting and were located on the eastern shore with similar topography and land use as Delaware. I used the main firearm season harvest data from the previously mentioned counties 4 years before (1999-2002), and after (2003-2006) Sunday hunting was allowed in Maryland. I compared the 4 year means of the main firearm season harvest before and after Sunday hunting was allowed to determine the percent increase in the Maryland main firearm season from Sunday hunting. The addition of Sunday hunting during the first weekend of the main firearm season in Maryland caused a 4% increase to the main firearm season harvest. Therefore, I increased the November shotgun season harvest by 4% to model the addition of Sunday hunting during the opening weekend in Delaware.

3.8.2 Adding 1 week to the November shotgun season

The main shotgun season in Delaware accounted for 46% of all the white-tailed deer harvested during 2005-2006 hunting season. The October muzzleloader season had the second highest harvest in the 2005-2006 season and only accounted for 12% of the total harvest. The main shotgun season in Delaware only lasts 9 days without Sunday hunting. Because the main shotgun season accounted for most of deer harvested in Delaware and it only lasted 9 days, I wanted to see if adding a 2^{nd} week, 6 days Monday through Saturday, would increase the over all deer harvest.

I used the Maryland harvest data from Caroline, Cecil, Dorchester, Kent, Queen Anne's, and Talbot counties because the main firearm season in Maryland lasted 2 weeks and the counties were located on the eastern shore with similar topography and land use as Delaware. I calculated the proportion of deer harvested during the 2^{nd} week of the main firearm season in Maryland by dividing the number of deer harvested in the 2^{nd} week by the total number of deer harvested during the main firearm season. I calculated the mean proportion of deer harvested during the 2^{nd} week of the Maryland firearm season for 8 seasons (1999-2006). I determined that the 2^{nd} week of the main firearm season in Maryland accounted for 22% of the total main firearm season harvest. I increased the Delaware November shotgun season harvest by 22% to model the addition of a 2nd week to the November shotgun season in Delaware.

3.8.3 Termination of the severe deer damage permits

In response to increased complaints from farmers about deer damaging agriculture crops, Delaware Fish and Wildlife managers initiated the deer damage assistance program in 1996. Farmers enrolled in the program were given free antlerless tags to harvest deer within the hunting seasons (J. L. Bowman, University of Delaware, unpublished report). In 2005, complaints from farmers about deer damaging agriculture crops caused managers to initiate the severe deer damage assistance program. The severe deer damage assistance program allowed farmers already enrolled in the deer damage assistance program for at least 1 year to harvest antlerless deer between 15 August and 15 May (J. E. Rogerson, Delaware Fish and Wildlife, personal communication)

I modeled the termination of the severe deer damage permits to determine if the severe damage assistance program was effective in reducing the deer population in Delaware. I removed the deer harvested under the severe deer damage permits from the 2005-2006 and 2006-2007 hunting seasons. I took the mean of the 2005-2006 and 2006-2007 hunting seasons with the severe deer damage permits removed. I divided the mean of the 2005-2006 and 2006-2007 hunting seasons with the severe deer damage permits removed by the 2005 population estimate. The result was the annual harvest rate for each zone and age class without the deer harvested under severe deer damage permits. I used the annual harvest rate without the deer harvested under severe deer damage permits to predict the future harvest and changes in the deer population.

3.8.4 Closing the October antlerless shotgun season

Delaware Fish and Wildlife managers created the October antlerless shotgun season in 2005 as a means to reduce the deer population. I modeled the closing of the October antlerless shotgun season to evaluate its success in reducing the population. I removed the deer harvested during the October antlerless shotgun season from the 2005-2006 and 2006-2007 hunting seasons. I took the mean of the 2005-2006 and 2006-2007 hunting seasons with the October antlerless shotgun season removed. I divided the mean of the 2005-2006 and 2006-2007 hunting seasons with the October antlerless shotgun season removed by the 2005 population estimate. The result was the annual harvest rate for each zone and age class without the deer harvested during October antlerless shotgun season. I used the annual harvest rate without the October antlerless shotgun season to predict the future harvest and changes in the deer population.

3.8.5 Closing the shotgun season in January, closing the muzzleloader season in January, and closing both the shotgun and muzzleloader seasons in January

The last 3 scenarios I modeled were the closing of the January shotgun season, closing of the January muzzleloader season, and closing both shotgun and muzzleloader seasons in January. I modeled the 3 scenarios at the request of Joe Rogerson the Delaware Fish and Wildlife game mammal biologist. Joe was interested in removing the January muzzleloader, shotgun, or both seasons to reduce conflicts on public hunting lands between deer hunters and other user groups. Removing one or both of the late January deer seasons could also reduce the number of shed bucks harvested as antlerless deer.

I modeled the closing of the January shotgun season by removing the deer harvested during the January shotgun season from the 2005-2006 and 2006-2007 hunting seasons. I took the mean of the 2005-2006 and 2006-2007 hunting seasons with the deer harvested during the January shotgun season removed. I divided the mean of the 2005-2006 and 2006-2007 hunting seasons without the deer harvested during the January shotgun season by the 2005 population estimate. The result was the annual harvest rate for each zone and age class without the deer harvested during the January shotgun season. I used the annual harvest rate without the January shotgun season to predict the future harvest and changes in the deer population. I used the same method to model the closing of the January muzzleloader season and closing both shotgun and muzzleloader seasons in January.

3.9 Carrying Capacity, Density Dependence, and Stochasticity

The carrying capacity, density dependence, and stochasticity functions of RAMAS metapop were not incorporated into the model. The carrying capacity function was not used, because I was unable to determine if any of the zone populations were at or nearing carrying capacity. Also, my search of the literature failed to find data that suggest a deer density when a population was near or at carrying capacity. Since I was unable to determine a carrying capacity, the density dependence function could not be used because RAMAS required I set a carrying capacity to limit the population growth as the population approached the carrying capacity. I did not use the stochasticity function. Delaware lacks hard winters with high snow fall and intense hurricanes, which can cause changes to the population density in other deer populations at the northern and southern parts of the white-tailed deer range. Also, the deer population size in Delaware is large enough, to avoid demographic stochasticity commonly seen in small isolated populations like the Florida Key deer (Lopez 2004).

Table 3.1 The fecundity and survival rates (± SD) used in the stage matrix of a spatially explicit model of the white-tailed deer population in Delaware, 2005-2014.

	Fecundity	Survival
Fawn Doe	0.05 (0.03)	0.83 (0.05)
Adult Doe	0.94 (0.02)	0.90 (0.06)
Fawn Buck	0.00	0.83 (0.05)
Adult Buck	0.00	0.89 (0.04)

Table 3.2 Survival and cause-specific mortality rates for white-tailed deer fawns, does and bucks reported in previous studies. I used the mean survival rates without hunting, vehicle, and predation to determine the survival rates used in the stage matrix of a spatially explicit model of the white-tailed deer population in Delaware, 2006.

Author	Reported Survival rate	Mortality: Hunting[1]	Vehicle	Predation[2]	Other[3]	Total	Survival Rate without Hunting, Vehicle, Predation
Fawn:							
Brinkman et al (2004)	0.84	0.00	0.02	0.06	0.08	0.16	0.92
Burroughs et al. (2006)	0.76	0.07	0.07	0.02	0.09	0.25	0.91
Huegel et al. (1985)	0.76	0.00	0.00	0.13	0.11	0.24	0.89
Nelson and Woolf (1987)	0.70	0.00	0.00	0.20	0.09	0.30	0.91
Rohm et al. (2007)	0.61	0.00	0.01	0.23	0.15	0.39	0.85
Vreeland et al. (2004)	0.57	0.08	0.06	0.07	0.22	0.43	0.78
Whickman et al. (1993)	0.78	0.14	0.03	0.00	0.05	0.22	0.95
Mean Fawn Survival Rate (SE)							0.89 (0.02)
Doe:							
Brinkman et al (2004)	0.79	0.11	0.05	0.02	0.04	0.21	0.96
Ebersol (2006)	0.79	0.15	0.04	0.00	0.02	0.21	0.98
Etter et al. (2002)	0.83	0.03	0.12	0.00	0.04	0.17	0.97
Nelson and Mech (1986)	0.84	0.03	0.00	0.11	0.03	0.17	0.98
Storm et al. (2007)	0.84	0.14	0.02	0.00	0.00	0.16	1.00
Whitlaw et al. (1998)	0.49	0.20	0.04	0.11	0.16	0.51	0.84
Mean Doe Survival (SE)							0.96 (0.02)
Buck:							
Bowman et al. (2007)	0.59	0.32	0.00	0.00	0.09	0.41	0.91
Ditchkoff et al. (2001)	0.73	0.15	0.02	0.02	0.08	0.27	0.92
Etter et al (2002)	0.83	0.00	0.17	0.00	0.00	0.17	0.83
Nelson and Mech (1986)	0.46	0.33	0.00	0.18	0.04	0.54	0.97
Mean Buck Survival (SE)							0.95 (0.02)

[1] Includes mortality from poaching, wounding loss and reported harvest
[2] Predation from bears, coyotes, and wolves
[3] Mortalities from natural and unknown causes, disease, drowning, predation from dogs, starvation, and trains

Table 3.3 The annual white-tailed deer vehicle mortality reported in previous studies. The mean was used to compare the Auto Insurance Industry value for estimated white-tailed deer annual vehicle mortality in Delaware.

Author	Annual Vehicle Mortality
Buck	
Bowman et al. (2007)	0.005
Ditchkoff et al. (2001)	0.021
Etter et al. (2002)	0.017
Doe	
Brinkman et al (2004)	0.054
Etter et al. (2002)	0.100
Porter et al. (2004)	0.186
Ebersol (2006)	0.042
Whitlaw et al. (1998)	0.087
Fawn	
Brinkman et al (2004)	0.024
Burroughs et al. (2006)	0.070
Rohm et al. (2007)	0.006
Whickman et al. (1993)	0.064
Total mean for Bucks, Does, and Fawns	0.069

Table 3.4 The white-tailed deer population and density of the 17 management zones in the State of Delaware, August 2005.

Zone	Population estimate	Deer Density per km^2
1	8642	40
2	2465	10
3	2053	10
4	1641	8
5	3317	13
6	1772	7
7	3952	17
8	3265	11
9	4518	16
10	1701	9
11	3955	14
12	2847	12
13	1251	6
14	3324	18
15	4036	16
16	5268	19
17	835	5
Total	54861	14

Table 3.5 The starting population numbers used in RAMAS Metapop for a spatially explicit model of the white-tailed deer population in Delaware, 2006. The deer legally harvested, poached, and fatalities from hunting related wounding during the 2005-2006 hunting season have been removed because the model starts in February 2006.

Zone	Fawn Doe	Adult Doe	Fawn Buck	Adult Buck	Total
1	1513	2971	1490	1301	7275
2	428	757	383	238	1806
3	355	610	301	162	1428
4	287	477	262	109	1135
5	526	883	491	290	2190
6	261	65	199	3	528
7	650	882	574	330	2436
8	553	818	536	248	2155
9	772	1245	699	473	3189
10	226	311	231	68	836
11	637	953	532	262	2384
12	410	566	383	187	1546
13	139	103	176	44	462
14	573	980	539	305	2397
15	713	1296	712	505	3226
16	891	1488	879	596	3854
17	139	140	106	25	410

Table 3.6 The percent of white-tailed deer mortalities from poaching and fatalities from hunting related wounding to the reported legal white-tailed deer harvest reported in previous studies.

Author	Poaching	Fatalities from hunting related wounding
Bowman et al. (2007)	22%	7%
Ditchkoff et al. (2001)	17%	-
Fuller (1990)	26%	10%
Nelson and Mech (1986)	9%	
Storm et al. (2007)	20%	-
Vreeland et al. (2004)	20%	
Whitlaw et al. (1998)	-	13%
Mean	19%	10%
Total poaching and fatalities from hunting related wounding		29%

Chapter 4

RESULTS

4.1 Calibration

I calibrated the model by adjusting the harvest and survival rates. I reduced the harvest rate by 15% for the 4 stages in all 8 scenarios. I reduced the survival rates in the stage matrix by 0.07 for the 4 stages. After the reductions, the predicted 2006-2007 harvest was 3% less than the actual harvest and the 2007-2008 predicted harvest was 3% greater than the actual harvest.

4.2 Scenarios

Without changing the current harvest regime, the state population decreased by 28% to 39,463 (68.11 SE) deer by the fall of 2014 (Figure 4.1). All zone populations decreased by 2014 without modifying the harvest regimes (Table 4.1). The scenario without changing the harvest regimes was used as a baseline to compare the effects of changing the harvest regimes in the other 7 scenarios.

The addition of Sunday hunting during the opening weekend of the main firearm season in Delaware caused a 3% increase to the mean harvest rate for the 4 stages (Table 4.2). The state population decreased 32% from the 2005 population estimate with the addition of Sunday hunting (Figure 4.1). By 2014, all zone populations decreased from the initial abundances in 2005 with Sunday hunting (Table 4.1). Adding a 2nd week onto the November shotgun season increased the mean harvest rate increased by 11% (Table

4.2). With the addition of a 2nd week on to the November shotgun season, the deer population decreased 41% from 2005 to 2014 (Figure 4.1). All of the zone populations decreased by 28% or more by 2014 (Table 4.1).

I found none of the harvest rates decreased in any of the 4 stages by more than 0.8% when I removed the deer harvested under the severe damage permits (Table 4.2). Terminating the severe deer damage permits still caused the state population to decrease by 25% in 2014 and all zone populations decreased as well (Table 4.1). Closing the October antlerless season caused a 6% decrease to the mean harvest rate (Table 4.2). The decrease to the harvest rate, particularly the adult doe harvest rate caused the predicted 2014 population in 5 of the zones to increase (Table 4.1). Despite the increases to some of the zone populations the state population still declined 12% from 2005 (Figure 4.1).

Closing the January shotgun season, January muzzleloader season, or both seasons caused the predicted 2014 population to increase in all 3 scenarios (Figure 4.1). With the January shotgun season closed, the mean harvest rate decreased by 7% (Table 4.2). Four zone populations increased, 2 zone populations remained the same, and the state population declined 12% from 2005 to 2014 (Table 4.1). Closing the January muzzleloader season caused the state population to decrease 20% by 2014 (Figure 4.1). All zone populations decreased from 2005 to 2014, except the zone 1 population increased (Table 4.1). Closing both shotgun and muzzleloader seasons in January had the greatest impact on the predicted 2014 deer population, than any of the 6 other hunting regime changes. The state population decreased 2% from 2005 to 2014 and 13 of the 17 zones had increasing populations (Table 4.1).

Table 4.1 The percent change of the 17 white-tailed deer management zones in Delaware from the 2005 population estimate to the 2014 predicted population for the 8 scenarios from a spatially explicit model of the white-tailed deer population in Delaware, 2005-2014.

Zone	No Change	Sunday Hunting Added	1 week added to November Shotgun Season	Severe Deer Damage Permits Terminated	October Antlerless Season Closed	January Shotgun Season Closed	January Muzzleloader Season Closed	January Shotgun and Muzzleloader Seasons Closed
1	-11%	-15%	-28%	-8%	9%	10%	-1%	22%
2	-19%	-23%	-34%	-15%	0%	1%	-9%	11%
3	-21%	-25%	-35%	-17%	-2%	-2%	-13%	8%
4	-21%	-27%	-37%	-18%	-5%	-5%	-13%	7%
5	-29%	-32%	-41%	-25%	-12%	-13%	-20%	-3%
6	-76%	-78%	-81%	-75%	-71%	-71%	-74%	-68%
7	-37%	-40%	-48%	-33%	-22%	-22%	-29%	-14%
8	-31%	-34%	-43%	-27%	-15%	-14%	-23%	-5%
9	-25%	-29%	-39%	-22%	-8%	-9%	-17%	1%
10	-48%	-51%	-58%	-46%	-37%	-37%	-43%	-30%
11	-33%	-37%	-46%	-31%	-18%	-18%	-26%	-9%
12	-44%	-46%	-54%	-41%	-31%	-31%	-38%	-23%
13	-71%	-72%	-76%	-70%	-65%	-65%	-68%	-61%
14	-22%	-25%	-37%	-17%	-4%	-3%	-12%	7%
15	-16%	-19%	-31%	-12%	4%	-4%	-6%	15%
16	-24%	-28%	-38%	-20%	-6%	-6%	-16%	4%
17	-49%	-51%	-58%	-46%	-37%	-37%	-43%	-30%
Total	-28%	-32%	-41%	-25%	-12%	-12%	-20%	-2%

Table 4.2 The difference in the predicted 2014 population and the mean harvest rate compared to the scenario without changing the harvest regimes and the 7 scenarios with modified harvest regimes in Delaware 2009-2014.

Scenario	Change in Population	Percent change in population	Change in Mean harvest rate	Percent change in harvest rate from no change scenario
No Change	0	0%	0.0000	0%
Permitting Sunday hunting during the opening weekend of the November firearm season	-2,007	-5%	0.0091	3%
Adding 1 week to the November shotgun season	-7,321	-19%	0.0370	11%
Termination of the severe deer damage permits	1,752	4%	-0.0040	-1%
Closing the October antlerless shotgun season	9,073	23%	-0.0201	-6%
Closing the shotgun season in January	9,079	23%	-0.0226	-7%
Closing the muzzleloader season in January	4,435	11%	-0.0107	-3%
Closing both the shotgun and Muzzleloader seasons in January	14,418	37%	-0.0333	-10%

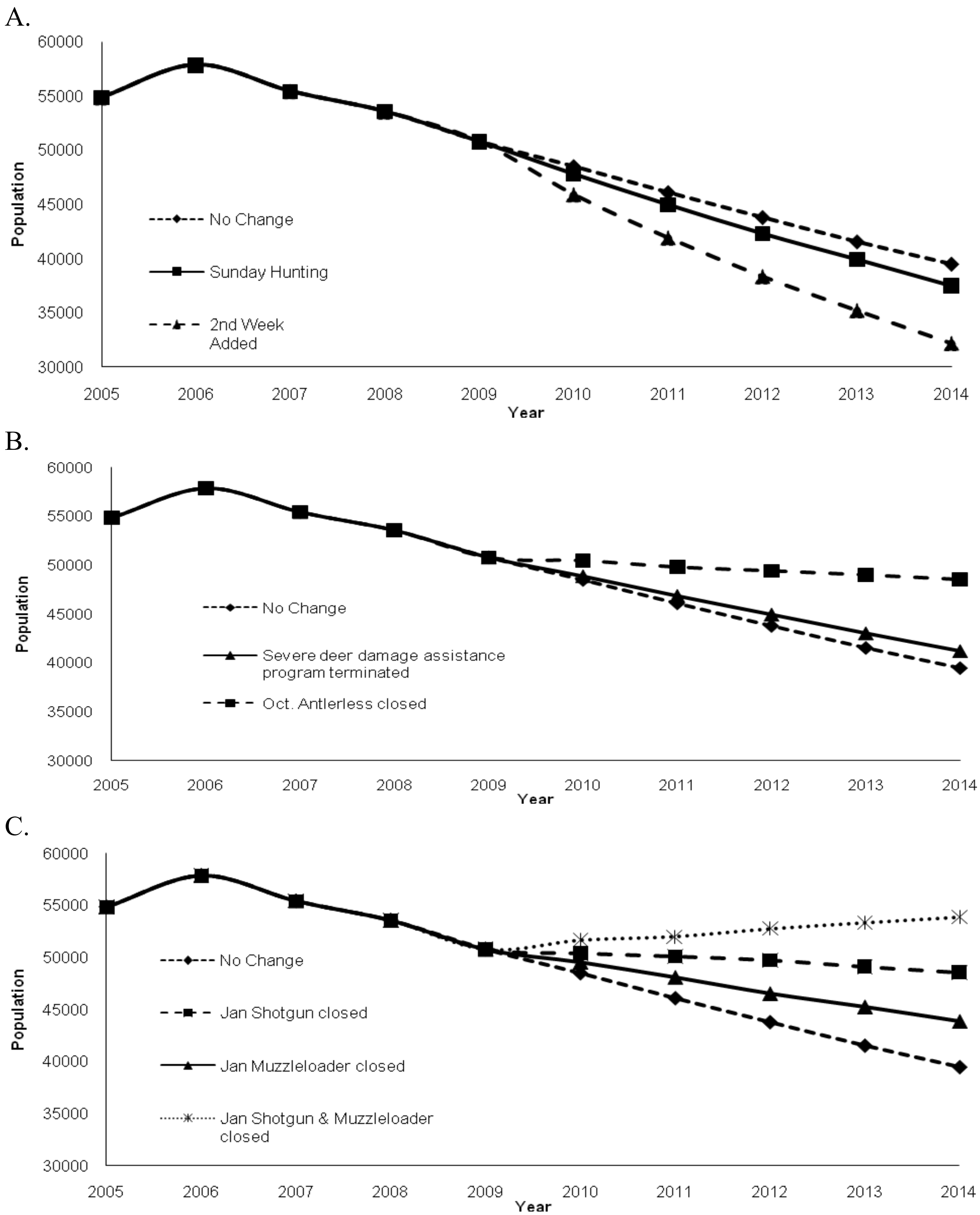

Figure 4.1 State of Delaware white-tailed deer population estimate from the spatially explicit model of the white-tailed deer population in Delaware beginning in August 2005 and ending August 2014. A. The addition of Sunday hunting and one week to the November shotgun season compared to no change in the harvest regime. B. The termination of the severe deer damage assistance program and closing the October antlerless season compared to no change in the harvest regime. C. Closing of the January shotgun and muzzleloader seasons compared to no change in the harvest regime.

Chapter 5

DISSCUSSION

Because the Delaware Fish and Wildlife managers did not have a model of the white-tailed deer population, I developed a model they could use to predict future populations. Not only does the model predict future populations, but it allows the managers to evaluate changes to the harvest regimes and implement the best regime to achieve management goals. In the future, managers will use the model to aid in the management of the white-tailed deer population.

5.1 Problems with the model

The accuracy of a model depends on the quality of the data used to construct the model and the assumptions made by the modeler. The method used to estimate the initial abundances from the FLIR survey could have overestimated or underestimated some of the zone populations and lead to some inaccuracies. The harvest rate used to predict future harvests was a fixed rate, but the actual harvest rate varies each year and would influence the predicted populations. The model predicted the deer population was declining under the current harvest regimes. I would expect the harvest rate to decrease because as the population decreases the probability of harvesting a deer should decrease with fewer deer available to harvest. Another problem with the harvest rate was correcting it for poached deer and deer fatalities from wounding related to hunting.

5.1.1 Initial population abundances

I assumed the 2005 population estimate was an accurate estimate of the white-tailed deer population; however, the accuracy of the 2005 population estimate is questionable. The population estimates of zones 6 and 13 were likely underestimated because the number of deer harvested in 2005-2006 and 2006-2007 were greater than the estimated population. FLIR surveys are the most accurate technique for a population census (Belant and Seamans 2000); however, FLIR is not 100 % effective because vegetation blocks the infrared beams preventing the detection of deer in dense vegetation (Belant and Seamans 2000). The reported detection rates, for the Delaware FLIR survey were 100% for agriculture fields and meadows, 86% for deciduous forests, and 50 – 80% for conifer forest depending on the canopy closure (Bernatas 2006). Bernatas (2006) or the Delaware Fish and Wildlife managers did not adjust the survey numbers for variation in detection rates. Some zone populations likely were underestimated because deer were not detected during the FLIR survey.

Delaware Fish and Wildlife contracted Vision Air to fly another FLIR survey between 25 February and 9 March 2009 currently, the data from the 2009 survey is still being analyzed (J. E. Rogerson, Delaware Fish and Wildlife, personal communication). The 2009 survey will help determine the accuracy of the first FLIR survey and the accuracy of the model predictions. If discrepancies occur with the model predictions then recalculating the 2005 population estimate, accounting for detection rates is one method to correct the model for accuracy.

5.1.2 Harvest rate

One of the limitations of using a fixed harvest rate is the number of deer harvested is dependent on the population size. Therefore, as the model population increases, the predicted harvest increases or as the model population decreases, the predicted harvest decreases. Steadman et al. (2004) and Bhandari et al. (2006) found factors other than deer population size, like number of hunters, weather, number of days spent hunting, distance from roads, and the type of deer harvested will affect white-tailed deer harvest. I used the average of the 2005-2006 and 2006-2007 harvests to account for the variables identified by Steadman et al. (2004) and Bhandari et al. (2006) that affect the harvest rate other than population size. Despite correcting the harvest rate for yearly variations related to hunter effort, the harvest rate is fixed in the model and I assumed the harvest rate would remain constant from the 2008-2009 hunting season through the 2013-2014 hunting season. The harvest rate may also increase or decrease based on the deer population size and not only on hunter effort.

I believe the population estimate was inaccurate in zones 6 and 13 because the number of deer harvested in 2005-2006 and 2006-2007 were greater than the estimated population of the respective zones. To correct for the inaccuracy of the FLIR population estimate, I used the mean harvest rate for the 17 zones, rather than the individual zone harvest rates. The problem with using the same harvest rate for all the zones was some zones had very different harvest rates. For example, the mean harvest rate of the 4 stages in zone 1 was 0.1767. The mean harvest rate of the 4 stages in zone 6 zone was 0.6914. The 4 stage, mean harvest rate I used to predict the harvest was 0.3217. Since mean harvest rate was used, the harvest in zone 6 maybe under estimated and the harvests in zone 1 maybe over estimated. The model predictions in 2014 at the state level maybe accurate within 5% of the actual population and harvest, but the zone level predictions in 2014 may not be accurate within 5%, making it difficult to manage the deer population on a zone level.

The harvest data I received from Delaware Fish and Wildlife represented the deer legally harvested and recovered. The Delaware harvest data did not report poached deer or deer fatalities from wounding related to hunting. I used previous research on cause specific mortality of white-tailed deer that reported mortality rates for poaching and wounding related to hunting. However, only 6 studies reported poaching mortality and 3 studies reported mortality from wounding related to hunting (Table 3.6). More research is needed to determine if the value I used to correct the Delaware harvest data was accurate.

5.1.3 Problems with RAMAS program

RAMAS was a good modeling program to use, but I encountered 2 problems. RAMAS reproduces the population before harvest occurs and does not let the user chose whether the harvest occurs before or after reproduction within the time step. I would have liked to have the harvest occur before reproduction because I could have started the model in August 2005 instead of February 2006 and not had to subtract the 2005-2006 harvest from the initial abundance numbers. Since I had to subtract the 2005-2006 harvest from the initial abundance numbers, there was a slight increase in the population from 2006-2007 then it began to slowly decline (Figure 4.1) The slight increase in the population occurred from not correcting for the inaccuracies of the FLIR population estimate in the 2005-2006 harvest. Since I used the actual 2005-2006 harvest and not the mean harvest rate used to predict the future harvest, the population increased.

The second problem I encountered was RAMAS only reported the combined harvest for the 17 zones and did not report the individual zone harvests unless each zone was modeled by itself. If RAMAS reported the individual zone harvest, I could have calibrated the model to the zone level harvest not the state level harvest, making the model predictions more accurate.

5.2 Scenarios

5.2.1 No change scenario

Without changing the hunting regimes, the Delaware white-tailed deer population increased in 2006 then began to slowly decline. The slowly declining trend is accurate, because hunter and landowner surveys indicate that throughout the state people are not seeing as many deer as in the past (J.E. Rogerson, DE Fish and Wildlife, personal communication). The declining population is a reasonable estimate assuming the harvest rates remain constant during the decline.

I believe some of the zones with more urban development will have increasing populations by 2014, rather than decreasing. In rural areas dominated by agriculture, hunting is the greatest source of mortality for white-tailed deer populations (Fuller 1990, Brinkman et al. 2004, Bowman et al. 2007). Changing the harvest regimes can be an effective population management tool because managers can control the number of deer harvested by changing bag limits and season lengths. Development is steadily increasing in the areas surrounding the cities of Wilmington, Newark, Dover, and Rehoboth. As development increases in the rural areas, many factors like safety zones surrounding buildings will reduce hunting access and create deer refuges (Brown et al. 2000). Deer refuges pose problems for wildlife managers using hunting as a management tool to control deer populations because the deer population can grow rapidly within the refuge, overpopulating it and the surrounding areas (Nixon et al. 1991, Brown et al. 2000).

5.2.2 Permitting Sunday hunting during the opening weekend of the November firearm season

The Maryland data showed adding 1 more day during the opening weekend of the main white-tailed deer firearm hunting season can increase the harvest. The success rate for harvesting a deer increases with the number of days spent hunting (Bhandari et al. 2006). An additional harvest day, especially a Sunday when most hunters do not have to work, will give most hunters another day to hunt. The additional day is important to help increase the harvest for hunters who harvest multiple deer. In Delaware 60% of the hunters harvest 1 deer and account for 40% of the harvest, the other 40% harvest 2 or more deer and account for 60% of the harvest (J. L. Bowman, University of Delaware, unpublished report). An additional harvest day, during the opening weekend of the main firearm season will increase the success rate for hunters who harvest multiple deer, which is important for reducing the deer population.

5.2.3 Adding 1 week to the November shotgun season

With the additional 6 days during the main shotgun season, the hunters who harvest more than 1 deer would have increased opportunities and success rates to harvest additional deer, increasing the harvest rate (Bhandari et al. 2006). I modeled the addition of the second week to the November shotgun season as a direct increase to the main firearms season. Unlike the addition of Sunday hunting, surrounding states have not recently added an additional week to their main firearm season. The lack of data from surrounding states makes it difficult to determine the effect an additional week on the main firearm season would have on the later hunting seasons. Hunters may become tired from hunting or stop hunting because they harvested enough deer during the second week of the November shotgun season and may not harvest deer during the late seasons in December and January. Due to the lack of data it is difficult to predict how much of an effect the additional week during the November shotgun season would have on the later deer seasons, which is why I modeled the additional week as a pure increase to the harvest rate.

5.2.4 Termination of the Severe Deer Damage Permits

The number of deer harvested under the severe deer damage assistance program was not enough to affect the statewide deer population. The effect of the severe deer damage permits is difficult to assess because my analysis evaluated the severe damage assistance program at the state level and not an individual property level. The program may work on a farm by farm basis to reduce crop damage, but not to reduce zone or state deer population levels.

Since the severe deer damage assistance program is voluntary, the landowners' properties not enrolled in the program may act as refuges that protect deer from harvest outside of the regular hunting season (Nixon et al. 1991, Brown et al. 2000). The deer populations in the refuges may restock the surrounding properties enrolled in the severe deer damage assistance program through dispersing migrants (Nixon et al. 1991). If the deer refuges are restocking the surrounding properties then I would not expect to detect a landscape effect when modeling the termination of the severe deer damage permits.

5.2.5 Closing the October antlerless shotgun season

Closing the October antlerless caused a decrease in the doe harvest rate sufficient to increase some zone populations, proving an antlerless only harvest is an effective method to increase the doe harvest and reduce a deer population (Nixon et al. 1991). The model data contrasts Brown et al. (2000) opinion that hunting is not a reliable method to control deer populations. Zone 1 has the highest deer population of all the zones and is the most developed. The deer population in zone 1 decreased by 11% from 2005 to 2014 with the October antlerless season open. When the October antlerless season was closed, the deer population in zone 1 increased by 9% from 2005 to 2014. The October antlerless season is important for increasing the harvest success of hunters more willing to harvest antlerless deer (Bhandari et al. 2006). Delaware Fish and Wildlife managers should evaluate the October antlerless season on a zone by zone basis and only close the season in zones with populations below desired levels.

5.2.6 Closing the shotgun season in January, closing the muzzleloader season in January, and closing both the shotgun and muzzleloader seasons in January

Delaware Fish and Wildlife managers can reduce conflicts between other user groups and deer hunters on public lands by closing the January shotgun or muzzleloader seasons and add additional firearm harvest days earlier in the season to maintain the current population trend. Delaware Fish and Wildlife managers could close the January shotgun season, add 6 days onto the November shotgun season, and allow Sunday hunting to maintain the current harvest and population predictions. If managers made the changes then the population trend would essentially be the same because closing the January shotgun season increased the population by 16% and adding 6 days to the shotgun season and allowing Sunday hunting caused a combined 17% decrease to the

2014 population. Managers could close the January muzzleloader season as well, but the managers will need to add additional harvest days on to other seasons like the December antlerless season. Bhandari et al. (2006) found successful antlerless hunters spent a greater number of days afield during the early and late seasons. Closing the January muzzleloader season caused the adult doe harvest mortality to decrease by 1.83%, almost 1% higher than the harvest mortalities of the other 3 stages. If Delaware Fish and Wildlife managers are concerned with decreasing the deer population and reducing conflicts on public lands then they should only close the late January shotgun or muzzleloader seasons if additional harvest days are added elsewhere.

Chapter 6

MANAGEMETN IMPLICATIONS

My model demonstrated that without modifying the harvest regimes the white-tailed deer population will decline by 28% in 2014. My model also showed that different zones had different population levels and harvest rates. Currently, harvest regime changes are statewide, and occur within all management zones, but to better manage the Delaware deer population, managers need to set harvest seasons and limits on a zone basis. If managers choose to manipulate the hunting seasons several options are available depending on the desired population level. Managers can further reduce the deer population by allowing Sunday hunting during the opening weekend of the main firearm season and/or adding an additional week onto the main shotgun season. If managers decide to slow or stop the population decline, then closing the October antlerless season and/or the late January seasons are the best methods. Terminating the severe deer damage assistance program is not an effective method to slow or stop the declining trend, because removing the deer harvested under the program only caused a 4% increase to the 2014 population. Depending on the desired 2014 population level, managers can adjust the harvest regimes accordingly to meet their population goals.

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