THE IMPACT OF CWD ON DEER HARVEST AND DETERMINING METHODS TO ESTIMATE DEER ABUNDANCE

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Wildlife Ecology

Fall 2013

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ACKNOWLEDGMENTS

I would like to first thank the students and faculty within the department whom have made my graduate experience so enjoyable. Many thanks to my advisor Jake Bowman who has helped my knowledge of wildlife research grow tremendously. To my committee members Kyle McCarthy and Brian Eyler, thank you for the valuable help and input. I am very appreciative of the hard work performed by George Timko, Chris Blakely, and Kelsey Schwenk collecting data in the field. The assistance of David Kalb in both the lab and field has been immeasurable. For my friends and family, your encouragement has meant the world to me as I've traveled across the country to pursue my career goals. Lastly, to my parents Mike and Beth Haus; every one of my achievements is a credit to your support, and I will never have the words to express my appreciation. I love you both very much.

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ABSTRACT

Chronic Wasting Disease (CWD) is a fatal neurological disease of North American deer species which has emerged as an important wildlife management issue. In 2010, a hunter harvested deer in Allegany County, Maryland tested positive for the disease. Herein, I examine 2 important aspects of CWD management in the state of Maryland. The first objective was to determine the impact of human dimensions, specifically negative hunter attitude towards CWD and restrictive management regulations, on deer harvest throughout the state. I used an attitude study completed by Responsive Management (Harrisonburg, VA) to identify hunters in 3 counties (Allegany, Garrett, and Dorchester) of varying proximity to the disease. Hunters were asked if and how CWD had caused them to alter their harvest behavior. I then linked each individual's response to their harvest history to determine the degree to which negative hunter attitude had reduced deer harvest. The amount of hunters who claimed to have changed their behavior due to CWD ranged from 14.08% in Dorchester County to 22.63% in Allegany County, suggesting distance to the disease affected attitude. In Allegany County, CWD caused a 6.95% average decrease in the annual harvest, which falls well within the normal stochastic variability in annual harvest. I observed no reduction in deer harvest attribuTable to CWD in Garrett or Dorchester Counties. My findings suggest that reduction in deer harvest after the discovery of CWD due to negative hunter attitude is highly localized near the disease management area and has little impact on deer management.

My second objective was to evaluate 3 common methods (spotlight and thermal-imaging road-based distance sampling and motion-triggered camera surveys) for estimating deer density and demographic parameters. I performed all 3 methods concurrently during 2 week sampling periods. Sampling periods occurred in August 2012, February 2013, and August 2013. Methodology comparison incorporated point estimates, measures of precision, detection probability, and cost. Camera surveys appeared to overestimate deer density, provided no measures of precision, and had a higher cost than road-based surveys. Spotlight surveys were affordable but required substantial effort to achieve the precision necessary for management decisions. Thermal-imaging surveys had greater detection probabilities relative to spotlight surveys and required less effort to achieve sufficient precision. I recommend road-based distance sampling incorporating thermal-imaging technology to estimate deer demographic parameters at the disease management unit scale.

Chapter 1

INTRODUCTION

Chronic Wasting Disease (CWD) is a transmissible spongiform encephalopathy (TSE) affecting deer (*Odocoileus spp.),* Rocky Mountain elk (*Cervus elaphus nelsoni*), and moose (*Alces alces*) (Williams and Young 1980, 1982, Kreeger et al. 2006). The disease is related to bovine spongiform encephalopathy (mad cow disease) and scrapie of sheep and goats that are of significant economic and public health concerns (Williams et al. 2002). CWD is associated with the presence of a protease–resistant prion (PrP^{cwd}) and is transmitted through direct or indirect contact with saliva, blood, urine, and feces (Williams et al. 2002, Mathiason et al. 2006, Gultiken et al. 2009) causing a fatal degenerative neurological condition. Infected individuals express symptoms such as increased drinking, excessive urination and salivation, erratic behavior, incoordination, stumbling, emaciation, listlessness, and eventually death (Williams et al. 2002). Originally discovered in a captive research facility in Colorado (Williams and Young 1980), 22 US states and 2 Canadian Provinces (Figure 1.1) now report positive cases of CWD in either wild or captive cervid herds (USGS National Wildlife Health Center 2012).

In 2011, 13.7 million people over the age of 16 spent $33.7 billion on hunting related expenditures in the United States. White–tailed deer (*Odocoileus virginianus*) were the most popular game species in North America, attracting nearly 11 million hunters (USDI 2012). Because of the economical benefits of deer hunting (Bishop 2004, Heberlein 2004), CWD is a major concern for biologists, managers, and stakeholders across North America (Williams et al. 2002, Shauber and Woolf 2003). Common CWD management protocol for white–tailed deer generally includes liberalizing bag limits and regulations, banning artificial feeding, restricting carcass translocation, and active surveillance to monitor disease prevalence and spread (Samuel et al. 2002, Williams et al. 2002, Wasserberg et al. 2009). The effectiveness of such practices are often difficult to determine as the lengthy incubation period (1 – 3 years from time of exposure to end-stage clinical disease) complicates disease detection (Williams et al. 2002, Schauber and Woolf 2003, Needham et al. 2004, Conner et al. 2007). Hunters are not likely to participate in management efforts without evidence of tangible results (Cooney and Holsman 2010), and the belief that aggressive population reduction will prevent hunters from observing or harvesting deer in the future is likely to result in distrust of wildlife professionals and a decline in hunter participation (Van Deelen and Etter 2003, Vaske et al. 2004). Additionally, fear of contracting the human variant TSE Creutzfeldt–Jakob disease (vCJD; McKintosh et al. 2003) from the consumption of venison from an infected deer may result in reduced hunter participation in disease management areas. No link between vCJD and CWD has been found, however the risk cannot be dismissed with absolute certainty (Raymond et al. 2000, Belay et al. 2004). Significant declines in hunter participation has several adverse effects on a typical CWD management strategy, including loss of revenue generated by license sales (Miller and Vaske 2003) and an increase in deer densities that may facilitate disease spread and compromise management goals (Enck 1996).

In 2010, the first positive case of CWD in the state of Maryland came from a yearling male harvested in the Green Ridge State Forest during the state's regular firearms season. Subsequent testing during the 2011 and 2012 seasons resulted in no additional cases (MDNR 2013*a*). The deer was shot less than 6 km from the West Virginia border, near to where 133West Virginia deer have tested positive for the disease since its discovery in 2005 (WV DNR 2013). Previous research in multiple CWD infected states has shown a small but significant decline in hunter participation after disease emergence (Bishop 2004, Heberlein 2004, Vaske et al. 2004), with a more precipitous drop likely as prevalence increases (Gigliotti 2004, Needham et al. 2004). In order for CWD management goals to be achieved, state wildlife managers must have a strong understanding of local deer abundance to justify management regulations and hunter attitude must be taken into consideration. The Maryland Department of Natural Resources (MDNR) called for a detailed herd assessment in the vicinity of the positive test as outlined in State's CWD Response Plan (MDNR 2011) and placed restrictions on artificial feeding and carcass translocation within an established CWD Management Area (CWDMA).

Several methods are used to obtain deer abundance estimates including, but not limited to, spotlight surveys (Progulske and Duerre 1964), thermal-imaging surveys (Wiggers and Beckerman 1993), motion-triggered cameras surveys (Jacobson et al. 1997), and mark–recapture studies (McCullough and Hirth 1988). Each method, however, is subject to unique biases that may produce estimates that do not reflect true dynamics of the populations of interest (McKinely et al. 2006; Roberts et al. 2006; Collier et al. 2007, 2013; McCoy et al. 2011). An evaluation of the cost, accuracy, and precision of each estimator must also be taken into consideration before management actions are implemented (Skalski et al. 2005). Additionally, the degree to which the presence of CWD and the related management actions has affected deer harvest within the Maryland CWDMA is unknown. The objectives for this study were two–fold. The first objective was to conduct a phone survey of Maryland deer hunters to determine if and how the presence and management of CWD impacted their hunting practices and affected harvest. The second objective was to compare the utility of 3 different deer abundance estimators, accounting for both spatial and temporal overlap, using cost and effectiveness as metrics to identify a preferred method to estimate deer density at the disease management unit scale. Chapters 2 and 3 of this thesis address the study's objectives and are formatted as manuscripts to be submitted to peer–reviewed journals.

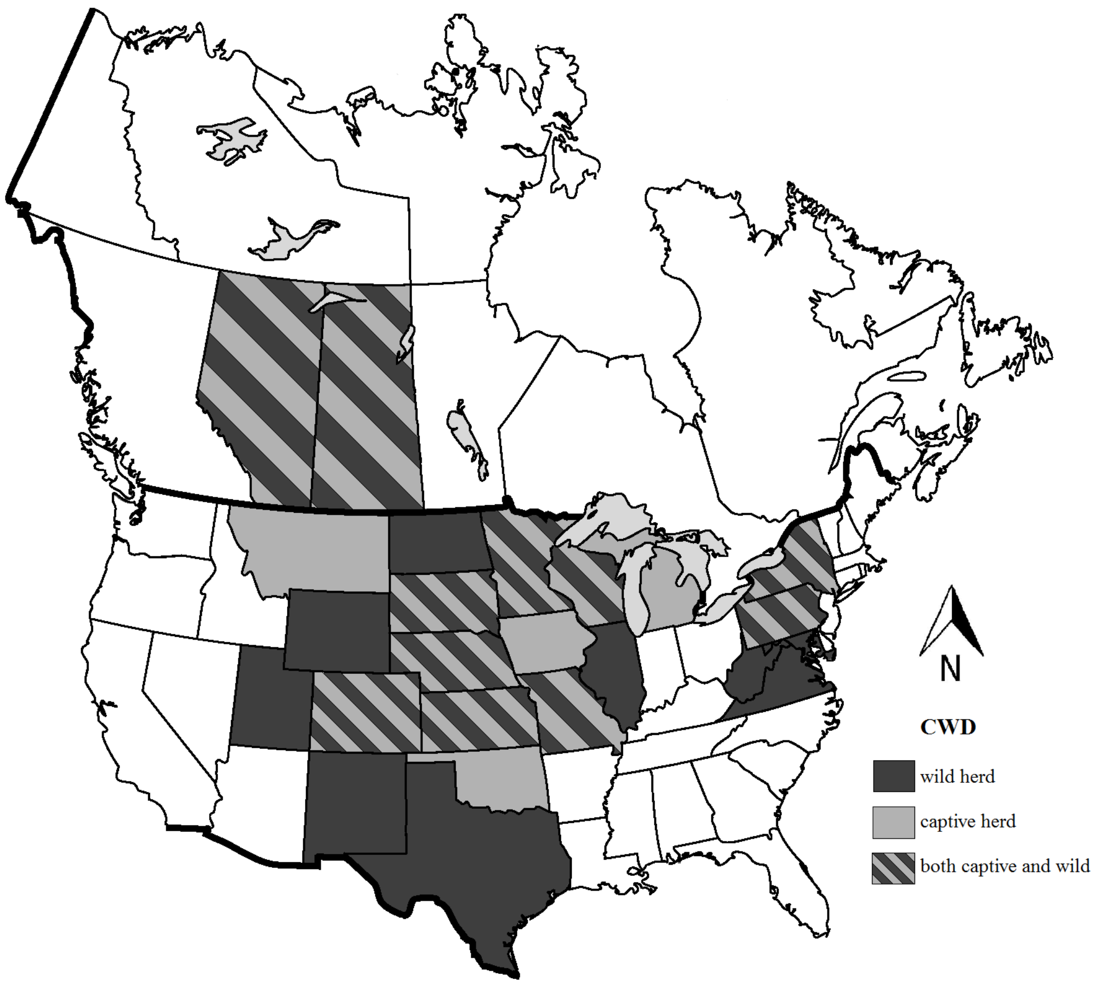

Figure 1.1 Map of 22 U.S. states and 2 Canadian provinces that have reported positive cases of Chronic Wasting Disease (CWD) in either captive or wild cervid herds as of 2013.

Chapter 2

HUNTER ATTITUDE TOWARDS CWD IN MARYLAND; IMPLICATIONS FOR HARVEST AND MANAGEMENT

Introduction

Chronic Wasting Disease (CWD) is a fatal neurological disease of deer (*Odocoileus spp.),* Rocky Mountain elk (*Cervus elaphus nelsoni*), and moose (*Alces alces*) (Williams and Young 1980, 1982, Kreeger et al. 2006) that is a major management concern for state biologists and stakeholders across North America (Enserink 2001, Williams et al. 2002). Disease management protocol for white–tailed deer (*O. virginianus*) generally involves localized population reduction through selective culling or liberalized harvest, banning of artificial feeding, and restriction on carcass translocation. Maryland reported the first case of CWD in the state when a yearling white–tailed buck harvested in southern Allegany County tested positive in 2010. The deer was killed 6 km north of the West Virginia border, a state that has reported 133 cases of CWD since 2005 (WV DNR 2013). The Maryland Department of Natural Resources (MDNR) reclassified the eastern portion of Allegany County (Harvest Management Unit 233) as a Chronic Wasting Disease Management Area (CWDMA). The state placed restrictions on carcass translocation and a ban of artificial feeding on both public and private lands within the CWDMA. Subsequent sampling from the 2011 and 2012 hunting seasons resulted in no additional positive cases in the state.

The incorporation of human dimension, specifically hunter attitude, into CWD management is an important step in developing a strategy to identify and address the negative human and biological impacts associated with CWD (Heberlein 2004). CWD management regulations are often unpopular with hunters, and determining the effectiveness of such regulations has been difficult (Schauber and Woolf 2003). Hunters are not likely to participate in management efforts without evidence of tangible results (Cooney and Holsman 2010). The belief that aggressive population reduction will prevent hunters from observing or harvesting deer in the future is likely to result in distrust of wildlife professionals and a decline in hunter participation (Van Deelen and Etter 2003, Vaske et al. 2004). Additionally, fear of contracting the human variant TSE Creutzfeldt–Jakob disease (vCJD; McKintosh et al. 2003) from the consumption of an infected deer may result in reduced hunter participation in the disease management areas. No link between vCJD and CWD has been found, however the risk cannot be dismissed with absolute certainty (Raymond et al. 2000, Belay et al. 2004). Significant declines in hunter participation has several adverse effects on a CWD management strategy, including loss of revenue generated by license sales (Miller and Vaske 2003) and an increase in deer populations that may facilitate disease spread and compromise management goals (Enck 1996). Pfieffer (2006) stated that stakeholder resistance to disease management regulations and erosion of public trust in scientific evidence cannot be solved by providing more information, but rather biologists should consider how hunter attitude influences disease management.

Wildlife managers are concerned that hunters' perceptions of risk associated with CWD may negatively affect their willingness to hunt in states where the disease is found (Gigliotti, 2004). There is an abundance of literature examining hunter attitude and potential behavioral responses to CWD (Miller 2003; Gigliotti 2004; Needham et al. 2004, 2007; Vaske et al. 2004; Stafford et al. 2007; Cooney and Holsman 2010). Research has suggested a small but significant decline in hunter participation after the emergence of CWD in many states (Bishop 2004, Heberlein 2004, Vaske et al. 2004), with a more precipitous drop likely as prevalence increases (Gigliotti 2004, Needham et al. 2004). Needham et al. (2007) reports that responses to CWD attitude surveys may be tied to the level of experience of an individual hunter, with more skilled hunters less likely to change their behavior than novice hunters. While a reduction in novice hunters has negative implications for future license revenue, the impact on deer harvest may be of less consequence than previously thought. Furthermore, McCleery et al. (2006) states that attitudes are often a poor predictor of behavior. An understanding of how hunter attitude affects harvest behavior in CWD infected areas is currently lacking. My objectives for this study were to both examine the effect of proximity to the disease on attitude and behavior of hunters, and to quantify the reduction in deer harvest attribuTable to shifts in behavior due to CWD.

Methods

Population Sampled

Responsive Management (Harrisonburg, VA) conducted an attitude survey of Maryland deer hunters in regards to CWD presence and disease management. The study entailed a telephone survey of deer hunters over the age of 18 who had checked a deer in one of 3 areas of varying proximity to the CWDMA within the last 5 years. I used amount of public hunting land and human density as criteria to select for similar areas. The areas included Allegany County, Garrett County (adjacent to Allegany County to the west), and Dorchester County (located over 200 km southeast of the CWDMA). I used a stratification of respondents to provide an understanding of how proximity to the CWDMA affected hunter attitude and the subsequent impact on harvest. Contact information was obtained from the MDNR deer registration records. Telephones were used as the preferred sampling medium because of the almost universal ownership among the sample of deer hunters. Additionally, telephone surveys allow for more scientific sampling and data collection, provide higher quality data, obtain higher response rates, are timelier, and more cost–effective relative to mail or internet surveys (Responsive Management 2013). The telephone survey questionnaire was developed in cooperation with Responsive Management and the MDNR. Telephone surveying times were Monday through Friday from 0900 – 2100 hr, Saturday from 1200 – 1700 hr, and Sunday from 1700 – 2100 hr, Eastern Time. The survey was conducted in August 2013. I received 1519 completed surveys (Allegany = 685, Garrett = 422, Dorchester = 412).

Survey Instrument

Because the survey was part of a larger evaluation, I used only a subset of attitudinal measures and demographic questions for this manuscript. I used 7 attitude statements about hunter behavior. These attitude statements were: 1) CWD has caused you to change where you hunt deer in Maryland; 2) CWD has caused you to deer hunt less in [county]; 3) CWD has caused you to deer hunt less in Maryland in general; 4) CWD has caused you to stop deer hunting completely in [county]; 5) CWD has caused you to stop deer hunting completely in Maryland; 6) CWD has caused you to stop hunting bucks in [county]; 7) CWD has caused you to stop hunting does in [county]. Respondents were asked if they “strongly agreed”, “agreed”, “disagreed”, “strongly disagreed”, “neither agreed nor disagreed”, or “don’t know” with each statement. Hunters who responded “don’t know” to all questions were censored from the analysis (n = 9). I blocked respondents on area and pooled hunters who responded strongly agree or agree to any statement into a “negative” group, and hunters who responded strongly disagree, disagree, or neither agree nor disagree to each statement into a “non–negative” group. I joined individual hunter responses with their 5 year deer harvest history. I split the harvest history into a 3 year pre-CWD period (2008 - 2009, 2009 -2010, and 2010 - 2011 hunting seasons) and a 2 year post-CWD period (2011 - 2012 and 2012 - 2013 hunting seasons).

I generated harvest rates for negative and non–negative hunters for both periods using the average number of deer harvested/individual/year. I calculated the change in average harvest rates among both non–negative and negative hunters using the difference between the pre– and post–CWD harvest rates. I used the difference between the change in harvest rates for non–negative hunters and the change in harvest rates for negative hunters to generate $\Delta harvest$ for each county;

$$\Delta harvest = (i - j) - (a - e)$$

where i = the average harvest rate for negative hunters pre–CWD, j = the average harvest rate for negative hunters post–CWD, a = the average harvest rate for non–negative hunters pre–CWD, and e = the average harvest rate for non–negative hunters post–CWD. $\Delta harvest$ was not vulnerable to stochastic variation in harvest (i.e. weather variables, mast abundance, deer abundance etc.), but instead was the post–CWD reduction in potential deer harvest rates among negative hunters that we could attribute to CWD and management regulations (Table 2.1). I then used the total number of hunters who had registered a deer within the last five years, the percent of negative respondents, and Δ *harvest* to extrapolate the average annual reduction in potential harvest for each county;

$$R = \Delta harvest * (H * h)$$

where R = the average annual reduction in harvest attribuTable to CWD, H = the total number of hunters who have registered deer between the 2008 – 2013 hunting seasons, and h = the percentage of hunters with negative attitudes (Table 2.2)

Results

Overall, 18.76% of all respondents claimed they had altered their behavior in some way due to CWD. The most common response among negative hunters was that CWD had caused them to change where they hunt deer in Maryland (12.64%).

Claiming to have hunted deer less, either in their respective county (5.13%) or in Maryland in general (5.07%) were the next most common responses. Claiming to have stopped deer completely in Maryland was the least common response (1.12%), followed by hunters who claimed to stop hunting in their respective counties (2.17%), and hunters who claimed to stop harvesting a specific sex (2.37% for both bucks and does) (Table 2.1).

Allegany County had the highest total percentage of negative respondents (22.63%), followed by Garret County (16.82%) and Dorchester County (14.08%) (Table 2.1). Allegany County also had the highest percentage of negative responses to each of the 7 statements. The difference between Garrett and Dorchester County hunters did not deviate by more than 1% in their responses to any statement. Allegany County respondents were more likely to hunt deer less in Allegany County than they were to hunt deer less in the State in general. Garrett and Dorchester County hunters, however, were more likely to limit their hunting statewide than hunt less in their counties (Table 2.1). All statements regarding hunters who stopped hunting in the state, their county, or stopped hunting a specific sex received less than 1% agreement in both Garrett and Dorchester Counties.

Only 3.16% (n = 48) of all respondents said they would either stop hunting completely in Maryland or their respective counties. Of all hunters who claimed to have stop hunting completely in Maryland (n = 17), 47.1% (n = 8) continued to register deer post–CWD. Additionally, of the 2.17% (n = 33) of hunters who claimed to have stopped hunting in their respective counties, 39.40% (n = 13) continued to register deer in those counties after CWD was discovered.

Prior to CWD, Allegany County hunters with negative attitudes had a similar harvest rate (0.62 deer/hunter/year) compared to non–negative hunters (0.59 deer/hunter/year). After the discovery of the disease, however, harvest rates fell in negative hunters (0.47 deer/hunter/year) and increased slightly in non–negative hunters (0.63 deer/hunter/year) (Figure 2.1), resulting in a Δ *harvest* of 0.195 deer/hunter/year. The resulting decrease in potential deer harvest that can be attributed to CWD is 285.60 deer/year in Allegany County, or a 6.95% reduction. In Garrett County, harvest rates for negative hunters (0.51 deer/hunter/year) were lower than for non–negative hunters (0.69 deer/hunter/year) prior to CWD. I observed no reduction in harvest rates among negative hunters after CWD discovery (0.51 deer/hunter/year). Non–negative hunter harvest rates decreased post–CWD (0.60 deer/hunter/year), leading to a Δ *harvest* of –0.085 deer/hunter/year. A negative Δ *harvest* value resulted in an increase in potential harvest of 103.05 deer/year among negative hunters after disease discovery. Negative hunters in Dorchester County increased their harvest rates post–CWD. Non–negative hunters had a greater change in harvest rate (Figure 2.1), leading to a Δ *harvest* of 0.081 deer/hunter/year. The subsequent reduction in potential Dorchester County deer harvest caused by negative attitudes towards CWD was 45.03 deer/year, a reduction of 1.52%. Random year to year variability in Allegany County deer harvest in the 5 years prior to CWD (2005 – 2010) averaged 12.64%, ranging from 2.87% to 29.07%. Garrett and Dorchester

Counties had much less variability in harvest, with an average annual fluctuation of 4.40% and 4.03% during the same time period, respectively (B. Eyler, MD Deer Project Leader; personal communication).

Discussion

Statewide hunter participation and retention were not likely affected by CWD, as very few hunters claimed to have stopped hunting completely and even fewer actually stopped hunting. In general, hunters with negative attitudes were more likely to shift where they hunted than they were to change how they hunted (amount of effort, species targeted). Negative hunters in Allegany County shifted their hunting to outside the county, while hunters from outside Allegany County concentrated their hunting within their county and were less likely to hunt elsewhere. Such an exodus of hunters from the disease management area may be an impediment to managers attempting to limit deer populations in these areas; however the overall impact on harvest appears to be minimal.

Average annual deer harvest prior to disease discovery, among hunters with negative attitudes towards CWD in Garrett and Dorchester Counties, was less than hunters with non–negative attitudes, supporting the claim of Needham et al. (2007) that more experienced hunters are less likely to express negative attitudes towards CWD and less likely to change their behavior. In Allegany County, however, hunters who expressed negative attitudes towards CWD had slightly greater harvest rates prior to CWD than did non–negative hunters.

Proximity to the disease was positively correlated with the percentage of negative attitudes. Hunters in Allegany County had considerably more negative attitudes regarding CWD, however outside Allegany County negative attitudes remain lower and fairly consistent throughout the state. It appears there is a highly localized increase in negative attitudes near the disease outbreak, but negative attitudes decrease to a sTable level as close as one county removed from the disease. Behavior changes resulting in harvest reduction were also correlated with proximity to the disease. The 6.95% decrease in Allegany County's harvest attribuTable to CWD was the greatest reduction observed among all 3 counties. Garrett County observed an increase of 103.05 deer/year attribuTable to CWD. Such an increase is almost certainly a function of random variability in harvest rather than a reflection of hunter behavior. Instead of associating negative hunter attitude with an increase in deer harvest; I considered the reduction in Garrett County harvest attribuTable to CWD to be 0%. The 1.52% reduction in Dorchester County was much more likely a result of random variability in harvest between negative and non–negative respondents than a result of an actual behavioral shift.

Teel et al. (2002) states that attitudes towards wildlife related issues influence behavioral intentions which impact behavior. Several researchers have expressed the importance of hunter attitude to a successful disease management plan (Miller 2003, Needham et al. 2004, Pfeiffer et al. 2006) with the assumption that negative attitude will drive problematic behavior changes. The disassociation of attitudinal and behavioral responses pertaining to wildlife management issues are well documented

(Wicker 1969, Upmeyer and Six 1989, McCleery et al. 2006). Social psychologists explain that because attitudes are cognitive events, they have no impact on the way respondents behave (Kim and Hunter 1993). I observed a disassociation between attitude and behavior in several hunters who registered deer after claiming to have stopped hunting. While such discrepancies are difficult to detect among respondents who claimed to have changed their behavior in other ways, disparity between attitude and behavior likely existed in all categories of responses. In general however, greater percentages of negative attitudes in Allegany County were associated with greater reductions in deer harvest. The disassociation of attitudes and behavior becomes apparent when hunters are removed from the disease however, as the negative attitudes expressed by Garrett and Dorchester County hunters resulted in no reduction of harvest.

A comparison between the percent reductions in harvest due to CWD with the normal stochastic variation in harvest provides insight into the actual impact of CWD on harvest. In Allegany County, the reduction in harvest of 6.95% due to CWD is far less than the average variability in harvest prior to CWD (12.64%) and on the lower end of the range (2.87% - 29.07%). The presence of CWD does not seem to impact harvest at a level greater than normal stochastic variation While Garrett and Dorchester County had much less average variability in year to year harvest (4.40% and 4.03%, respectively) the observed reduction of 0% in Garrett and 1.52% in Dorchester Counties were both inconsequential considering normal variation in harvest. Given the relatively low variability in annual harvest however, the potential exists for CWD to have a greater impact on harvest relative to the stochastic norm should the disease spread to those areas.

An important caveat to an attitude study of Maryland deer hunters is the fact that the State had only 1 positive case of CWD statewide. As of July 2011, Hampshire County, West Virginia had reported 99 positive cases of CWD. Hampshire County borders Allegany County to the south and the Maryland CWD positive deer was harvested only 6 km from the Hampshire County border. In 2011, Responsive Management (Harrisonburg, VA) performed a similar survey of Hampshire County deer hunter attitudes towards CWD (Responsive Management 2011). 29% of respondents claimed they have altered their hunting behavior due to the presence of CWD, with 10% claiming to have changed where they hunt. These values closely resemble responses of Allegany County deer hunters, suggesting disease prevalence has little influence on overall hunter attitude.

Management Implications

While the number of hunters expressing negative views towards CWD and management regulation may be alarming to state managers, changes in hunter behavior have little impact on harvest. Additionally, changes in behavior appear to be strictly localized and to have no implications outside the disease management area. Upon initial detection of CWD, managers should implement appropriate and necessary protocols for disease reduction and containment with the understanding that while hunters may vocally oppose such practices, reductions in harvest will be negligible. Additionally, managers should not base decisions regarding human dimensions of

CWD management on attitude surveys without incorporating some measure of behavior.

Table 2.1 Harvest rates for hunters with negative and non-negative attitudes towards CWD both before (2008 – 2010) and after (2011– 2013) disease discovery in 3 counties of varying proximity to the disease management area in Maryland, USA.

County	i[a]	j[b]	a[c]	e[d]	$(i-j)$	$(a-e)$	$\Delta harvest$[e]
Allegany	0.624	0.468	0.594	0.633	0.156	-0.039	0.195
Garrett	0.507	0.507	0.689	0.604	0.000	0.085	-0.085
Dorchester	0.822	0.862	0.988	1.109	-0.040	-0.121	0.081

a. The average harvest rate for negative hunters pre–CWD.
b. The average harvest rate for negative hunters post–CWD.
c. The average harvest rate for non–negative hunters pre–CWD.
d. The average harvest rate for non–negative hunters post–CWD.
e. The reduction in harvest rates for negative hunters attribuTable to CWD.

Table 2.2 The total number of hunters who have registered deer in the last 5 years (2008 – 2013), the percentage of hunters with negative attitude towards CWD, the reduction in deer harvest due to CWD and the normal variability in harvest in the 5 years prior to CWD (2006 – 2010) in 3 counties of varying proximity to the disease management area in Maryland, USA.

County	H^a	h^b	R^c	$\%R^d$	$\%PRE^e$
Allegany	6472	22.63	285.60	6.95	12.64
Garrett	7208	16.82	$0^{\perp}$	$0^{\perp}$	4.40
Dorchester	3948	14.08	45.03	1.52	4.03

a. The total number of hunters who have registered deer in the previous 5 seasons (2008 – 2013).

b. The percentage of hunters with negative attitudes towards CWD.

c. The predicted average annual reduction in deer harvest due to CWD expressed in number of deer.

d. R as a percent reduction.

e. The average stochastic variability in harvest 5 years pre-CWD discovery (2006 – 2010).

$\perp$. Garrett County observed a negative reduction in harvest due to CWD; for analysis purposes R is considered 0.

Table 2.3 Percentage of respondents who either agreed or strongly agreed to 7 statements regarding behavioral changes in response to CWD in a survey performed by Responsive Management of hunters from 3 counties of varying proximity to the disease management area in Maryland, USA, 2013.

Statement	Total	Allegany	Garrett	Dorchester
CWD has caused you to change where you hunt deer in Maryland.	12.64%	15.91%	10.19%	9.71%
CWD has caused you to deer hunt less in [county].	5.13%	9.34%	1.90%	1.46%
CWD has caused you to deer hunt less in Maryland in general.	5.07%	6.72%	4.03%	3.40%
CWD has caused you to stop deer hunting completely in [county].	2.17%	4.23%	0.47%	0.49%
CWD has caused you to stop deer hunting completely in Maryland.	1.12%	2.19%	0.00%	0.49%
CWD has caused you to stop hunting bucks in [county].	2.37%	4.67%	0.24%	0.73%
CWD has caused you to stop hunting does in [county].	2.37%	4.96%	0.24%	0.24%
Agree to any of the above statements.	18.76%	22.63%	16.82%	14.08%

A.

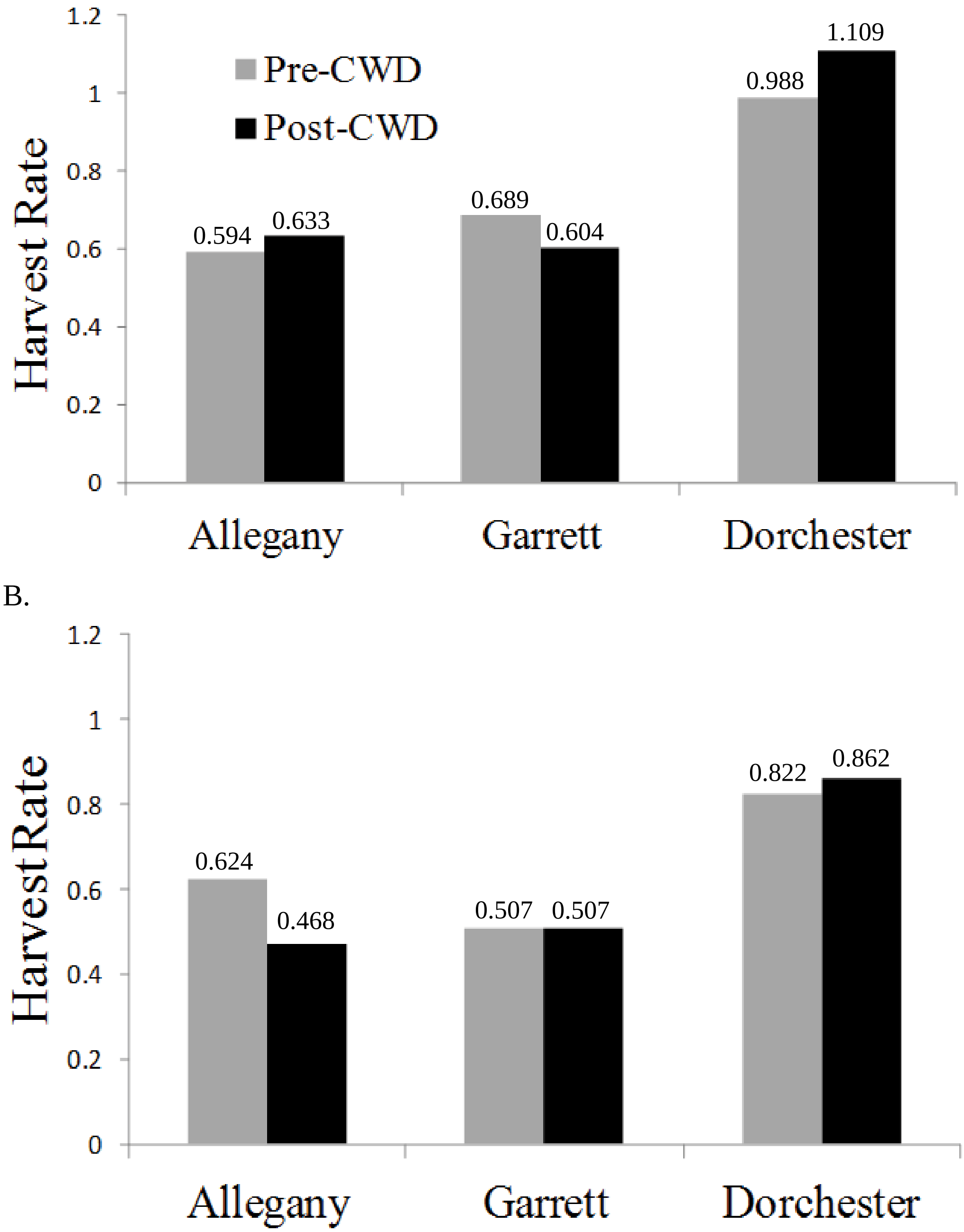

Figure 2.1 The average annual deer harvest (number of deer killed/hunter/year) for hunters with Non–negative (A) and Negative (B) attitudes towards CWD 3 years prior to disease discovery (2008 – 2009, 2009 – 2010, 2010 – 2011) and 2 years post disease discovery (2011 – 2012, 2012 – 2013) for 3 counties in Maryland, USA.

Chapter 3

A SPATIALLY AND TEMPORALLY CONCURRENT COMPARISON OF POPULAR DEER ABUNDANCE ESTIMATORS

Introduction

White–tailed deer (*Odocoileus virginianus*) are a species of incredible importance to wildlife managers throughout North America (Waller and Anderson 1997). Deer are valued for consumptive and non–consumptive recreation alike (Conover 1995) and the revenue generated through hunting related expenditures is the largest source of funding for state wildlife agencies (Jacobson et al. 2010). An overabundance of deer can be detrimental however; degrading forest communities (Tilghman 1989, Russel et al. 2001, Rossell et al. 2005), causing significant economic losses and damage to personal property (Conover et al. 1995, Romin and Bissonette 1996, Bissonette et al. 2008), and facilitating the spread of diseases such as Lyme disease (Rand et al. 2003) and Chronic Wasting Disease (Williams et al. 2002, Kjaer et al. 2008). A means for estimating deer demographic information as well as monitoring population trends over time is a necessary tool for sound deer management (Jacobson et al. 1997, Gibbs 2000). Such tools, however, are often limited by accuracy, reliability, and cost (Jenkins and Marchington 1969). Several methods for obtaining abundance and demographic estimates exist, but each is subject to biases and limitations that hinder reliability. Pellet counts (Eberhardt and Van Etten 1956, Neff 1968), spotlight surveys (Progulske and Duerre 1964, McCullough 1982), aerial counts (Caughley 1977, Potvin et al. 2002), mark–recapture studies (McCullough and Hirth 1988), herd reconstruction from harvest data (Roseberry and Wolf 1991, Millspaugh et al. 2009) and motion–triggered camera surveys (Jacobson et al. 1997, Koerth and Kroll 2000) are methods commonly used to generate estimates, but vary in efficiency and cost. Many studies have attempted to evaluate the utility of these methods, but accuracy is difficult to determine without knowledge of true abundance. Researchers have attempted to overcome such issues by generating estimates from captive deer herds of known abundance (Potvin and Breton 2005, McKinley et al. 2006, McCoy et al. 2011), however DeYoung et al. (2006) advises caution when extending the results of captive studies to free–ranging deer as behaviors may be markedly different. Additionally, studies have approached the issue by using multiple methods to generate estimates for the same population (Naugle et al. 1996, Roberts et al. 2006, Urbanek et al. 2012). Due to logistical constraints, many of the latter studies perform comparisons of estimates obtained over different spatial and temporal scales. Deer behavior, such as movement patterns and habitat use, is affected by a number of factors, including but not limited to temperature, snow depth, and food availability (Beier and McCullough 1990), which can vary markedly over minute spatial and temporal scales. Failing to account for such variation likely negatively affects estimate comparisons.

Distance sampling via road spotlight counts remains the most commonly used survey method because of the method's low cost and simplicity (Fafarman and DeYoung 1986, Whipple et al. 1994, Buckland et al. 2001); however, variable detection probability, observer bias, and animal disturbance may limit accuracy (McCullough 1982, Belant and Seamans 2000, Collier et al. 2007, 2013). Forward looking infrared (FLIR) equipment has been integrated into distance sampling methods in an attempt to increase detection and limit animal disturbance, but high initial cost of the unit may negate any benefit (Belant and Seamans 2000, Focardi et al. 2001). Additionally, convenience sampling of road transects has been a widely criticized study design for the potential bias associated with non–random transects (Anderson 2001, Ellingson and Lukacs 2003).

Motion–triggered trail cameras (hereafter; cameras) have steadily gained in popularity as a survey tool with the advancement of digital technology and the commercial availability of camera units (Jacobson et al. 1997, Cutler and Swann 1999, Koerth and Kroll 2000). Camera surveys can be less labor intensive and less invasive (Cutler and Swan 1999, Rowcliffe et al. 2008) compared to other survey methods and are not limited by thick vegetation, weather, or observer bias (Larrucea et al. 2007, Rowcliffe et al. 2008). Jacobson et al. (1997) developed a survey method (hereafter; Jacobson method) to estimate deer population size by enumerating the photographic rate of adult males using uniquely identifiable antler characteristics and extrapolating that rate to the remaining population. The Jacobson method has been criticized for failure to generate measures of precision (Curtis et al. 2009) and the assumption of equal detectability among age and sex classes which may not be met (McCoy et al. 2011). Camera surveys are also limited to specific seasons (McKinley et al. 2006) and highly dependent on the use of bait (Koerth and Kroll 2000), which may not be legal in many areas.

As spotlight, FLIR, and camera surveys continue to be used to estimate deer density, the effectiveness of each method should be evaluated and compared with alternative estimators in order to evaluate effectiveness (Collier et al. 2007). My objective was to generate demographic and density estimates using spotlight and FLIR road-based distance sampling as well as camera surveys for the same population of deer over multiple survey periods. Estimates were obtained using strict spatial and temporal homogeneity to meet assumptions of population closure that may have influenced previous studies.

Study Area

I conducted my research on a 2000 ha section of the Green Ridge State Forest (GRSF) located in eastern Allegany County, Maryland. The study area was located near Stafford Ridge in the center of GRSF (39°36'49"N, 78°28'24"W). GRSF was open to public deer hunting from 7 September through 31 January during the study period.

Late successional forests comprised >90% of the landscape in GRSF. Dominant overstory species included chestnut oak (*Quercus prinus*), northern red oak (*Quercus rubra*), pignut hickory (*Carya glabra*), red hickory (*Carya ovalis*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), swamp white oak (*Quercus.bicolor*), interspersed with occasional Virginia pine (*Pinus virginiana*) and white pine (*Pinus strobus*) (Maryland Department of Natural Resources 2012). Common midstory and understory species include northern highbush blueberry (*Vaccinium corymbosum*), flowering dogwood (*Cornus florida*), greenbriar (*Smilax spp*.), eastern redbud (*Cercis canadensis*), and sassafras (*Sassafras albidum*). The GRSF ranged in elevation from 152 m along the Potomac River to 620 m at the highest ridge (Evans and Gates 1997). Average temperature (1981 – 2010) ranged from a winter low of –5.33°C in January to a summer high of 31.06°C in July (USNOAA 2013). Allegany County received an average (1981 – 2010) of 95 cm of precipitation each year (USNOAA 2013). Weather conditions during the study period did not diverge from the 30 year (1981 – 2010) monthly averages (August and February; USNOAA 2013).

Methods

I conducted all survey methods during 3 separate 14 day periods (7–20 August 2012, 1–14 February 2013, and 7–20 August 2013). I drove road transects for distance sampling 12 of 14 nights. I performed spotlight and FLIR surveys on alternating nights for a total of 6 replicates per period each with 2 nights allotted for inclement weather. I maintained cameras and bait sites through the duration of the 14 day survey period.

Surveys began 1 hour after sunset, with start and stop locations constant across survey nights and survey periods. The survey route followed continuous roads throughout the study area for a total of 45 km (Figure 2.1). A two person team (driver and observer) traveled at a speed not exceeding 20 km/hr and surveyed only the right side of the road. To avoid bias, the same observer (J. Haus) was used for the duration of the study. Directionality of the survey route was every second day to ensure both sides of the road were surveyed an equal number of days per period. The observer used spotlight and FLIR unit on alternating nights. The observer used a 12–volt spotlight (Cyclops Solutions LLC, Grand Prairie, TX) for spotlight surveys and a Thermal–Eye 250D Digital FLIR device (L–3 Communications Infrared Products, Dallas, TX) for FLIR surveys to continuously search for deer. When a deer or cluster of deer were observed, the observer used a spotlight to determine the sex and age (adult/fawn) of each individual, and the perpendicular distance to the cluster. The observer recorded distance to the original position if deer were observed moving in response to the approaching vehicle. Distance estimates were obtained using a laser rangefinder (Leica Camera AG, Solms, Germany; ± 1 m accuracy). I used a kestrel pocket weather meter (Nielsen–Kellerman Co., Chester, PA) to obtain and record weather data for each night; including temperature, wind speed, relative humidity, precipitation, and barometric pressure. I used Program DISTANCE 6.0, version 2 (Thomas et al. 2009) to estimate density. I analyzed distance sampling data with both the Convention Distance Sampling (CDS) model and the Multiple Covariate Distance Sampling (MCDS) model. Weather measurements acted as covariates in the MCDS model, however underlying model structure was similar to CDS. Model selection was performed using Akaike Information Criterion corrected for small sample size (AIC_c; Hurvich and Tsai 1989). The models with the lowest AIC_c value were considered to have more support and be more parsimonious than models(i) with $\Delta_i AIC_c$ ($\Delta_i AIC = AIC_{ci} - AIC_c min) \geq 2$ (Burnham and Anderson 2002, Posada and Buckley 2004).

Camera sites were established in accordance to Jacobson et al. (1997). The study area was divided into 20 square 100 ha grid cells (Figure 2.1) with a Reconyx HC–600 infrared camera (Reconyx Inc., Holmen, WI) placed at the center, however exact placement was adjusted to provide ease of access and increase likelihood of visitation by deer (Jacobson et al. 1997). Grid size was based on the average annual home range size of adult deer (113[SE = 18] ha) in a comparable habitat within the Appalachian Mountain range (Campbell et al. 2004). I used a handheld GPS unit (Garmin Ltd., Olathe, KS) to mark locations of camera sites. All cameras were oriented north and had vegetation and debris cleared from the area to prevent sun glare and false triggers. Camera sites were baited with 11 kg of shelled corn placed approximately 5 m from the camera. A camera survey pilot study conducted in July 2012 concluded that a pre–baiting period was unnecessary as deer readily found and consumed bait on day 1, and photographic rates did not increase during subsequent days. Cameras were active for 14 days on 24 hour capture mode with a 3 minute delay, taking 3 photographs per event over a period of 20 seconds. The pilot study found that deer averaged 4 to 6 minutes feeding at a bait site. A 3 minute delay preserved battery life and reduced the amount of repeat pictures of a single individual, while ensuring that deer visiting the bait site without being photographed was unlikely. The use of 3 photographs per event provided multiple angles of antlered males that aided in identification. I checked camera sites every third day to change memory cards and replenish bait sites.

I compiled and analyzed all photographs by camera site at the end of each 14 day survey period. I followed methods previously described by Jacobson et al. (1997) for photograph analysis. I used distinguishable antler characteristics to uniquely identify individual males. I tallied buck, doe, and fawn Images. Total counts included known repeats of individuals. I divided the total number of unique bucks by the total number of buck images to get a population multiplier (unique bucks-to-total buck images). I applied this multiplier to the total images of does and fawns to get an estimated number of unique does and fawns for the survey area. I added those estimates to the known number of individual bucks for an overall abundance estimate. I applied the abundance estimate to the known area of the camera grid to generate a density estimate.

My study used estimates from a population of unknown deer abundance, meaning I could not evaluate estimated based on accuracy. I compared estimates within survey periods using point estimates (number of deer/km^2), 95% confidence interval (CI) overlap, percent coefficient of variation (CV), detection probability, and cost, to evaluate the effectiveness of each method at the management unit scale. I concluded that methods generated different estimates if there was no overlap in CIs. An estimate was considered sufficient for management decisions if CV < 25% (Skalski et al 2005). Costs estimates were generated for each method and averaged across survey periods. I assumed that all equipment would last 5 survey periods and cost of equipment/survey period was adjusted accordingly. Cost of labor was estimated using a rate of $12.00/hour/employee and categorized by field labor and analysis labor. Mileage costs were estimated using a rate of $0.55/mile.

Results

MCDS models incorporating weather covariables received far less support and were less parsimonious than CDS models for both spotlight (Table 3.1) and FLIR (Table 3.2) across all survey periods. Method comparisons were performed using only the CDS models.

During the August 2012 survey period, I observed 52 and 60 clusters of deer with spotlight and FLIR surveys, respectively. FLIR surveys resulted in a higher detection probability (0.57) than spotlight surveys (0.51). The CI estimates for deer density had considerable overlap for spotlight and FLIR surveys; however the spotlight density estimate was less precise and lacked sufficient precision for management decisions. Camera surveys resulted in 14,486 deer images and 58 identifiable bucks and a density point estimate well outside the upper CIs of both distance sampling methods (Figure 3.2). Demographic estimates were highly variable (Table 3.4), with FLIR surveys producing the highest adult sex ratio (2.7:1; does:buck) and fawn recruitment (0.46; fawns per doe). Camera surveys generated a moderate adult sex ratio (2.5:1) and the lowest estimate of fawn recruitment (0.28). Spotlight surveys resulted in the lowest estimate of adult sex ratio (2.0:1) and a moderate estimate of fawn recruitment (0.38).

During the February 2013 survey period, I observed fewer clusters of deer (42) and a lower detection probability (0.32) during spotlight surveys relative to FLIR surveys (46 and 0.45, respectively). I again observed a high amount of CI overlap, although both distance sampling techniques failed to generate sufficient precision for management. The camera survey resulted in 14,214 deer images and 25 identifiable bucks for a density point estimate that was again greater than spotlight and FLIR estimates and well outside both upper CI limits (Figure 3.2). I was unable to estimate demographic information for FLIR and spotlight methodologies during the February 2013 survey period due to difficulty discerning adult does, fawns, and adult males that had shed antlers. Cameras allowed for a more detailed examination of body characteristics, and resulted in an adult sex ratio estimate of 3.1:1 and a fawn recruitment estimate of 0.63.

The recorded harvest within the study area during the 2012 – 2013 hunting season was 2.13 deer/km^2 (MDNR 2013*b*). Between the August 2012 and February 2013 survey periods, FLIR and spotlight estimates showed a reduction in density of 3.05 and 2.84 deer/km^2, respectively, while cameras only estimated a reduction of 0.39 deer/km^2. However, the recorded antlered harvest in the study area was 1.30 deer/km^2 (MDNR 2013*b*), which was identical to the observed reduction in identifiable bucks based on demographic estimates generated by the camera surveys

I recorded 45 clusters of deer with detection probability of 0.35 using a spotlight and 58 clusters of deer with a detection probability of 0.36 using a FLIR during the August 2013 survey period. Density estimates for the distance sampling methods noticeably diverged (Figure 3.2) however estimates were not considered to be disparate as I again observed CI overlap. Both density estimates provided sufficient precision for management decisions. Cameras recorded 10,995 deer images and 40 identifiable bucks, resulting in a density point estimate well within the bounds of FLIR survey CI, but greater than the upper CI limit of spotlight surveys (Figure 3.2). Estimates for adult sex ratio were less variable than during the August 2012 survey period, with FLIR and spotlight producing identical estimates (2.3:1) and the camera surveys only slightly greater (2.4:1). Estimates of fawn recruitment were again highly variable. Similar to the August 2012 survey period, cameras produced the lowest estimate of fawn recruitment (0.36) during the August 2013 survey period; however the estimate from spotlight surveys was much increased (0.74). FLIR surveys again estimated a fawn recruitment rate of 0.46 (Table 3.4).

FLIR and spotlight surveys had identical costs for mileage and labor, however high cost of the FLIR unit resulted in an increase of $1,580 per survey period relative to spotlight costs. Camera surveys involved significantly higher equipment cost, more hours in the field, and more intensive data analysis resulting in an increase of $3,633.49 and $2,053.49 per survey period relative to spotlight and FLIR surveys, respectively (Table 3.5).

Discussion

A conclusion regarding which method generated the most accurate estimates is difficult to make as I surveyed an open deer population of unknown abundance and demography. Although spotlight surveys consistently estimated the lowest density during each survey period, CI overlap suggested no difference in estimates produced by spotlight and FLIR surveys. Density estimates from cameras differed from both distance sampling techniques in the August 2012 and February 2013 survey periods and from spotlight surveys in August 2013. During the February survey period, FLIR surveys were similar to both camera and spotlight surveys. FLIR surveys appeared to provide conservative density estimates with adequate precision compared to spotlight and camera surveys.

Focardi et al. (2001) reported no difference in the performance of spotlight and FLIR techniques in species possessing a tapetum lucidum; however, my results indicate a reduced probability of detection leading to less precision in spotlight surveys. Furthermore, forest cover and steep elevation likely hindered detection probability in both distance sampling methods. Habitat features (i.e., elevation, rivers, cover type) influenced location of transects (roads) and likely dictated the distribution of the deer population, which resulted in a violation of experimental design and introduced potential bias to detection and thus density estimates (McShea et al. 2011). Precision was not sufficient for management decisions (CV < 25 %; Skalski et al. 2005) for spotlight estimates in 2 survey periods (August 2012 and February 2013) and 1 survey period (February 2013) for FLIR surveys. The seasonal difference for both methods between August 2012 and February 2013 matches the recorded harvest for the area, which supports past research advocating distance sampling as a means to monitor population trends (Fafarman and DeYoung 1986, Whipple et al. 1994, DeYoung 2011). I detected no discernible advantages of either distance sampling technique when estimating demographic parameters.

With Jacobson camera surveys, the assumption of equal detectability is essential to density estimates and is based on detection probability of individually identifiable bucks. Jacobson et al. (1997) stated that bias by gender would bias estimates of deer populations. Past research has documented such gender specific bias of camera surveys (Jacobson et al. 1997, Cutler and Swann 1999, Larrucea et al. 2007). Behavioral responses to baiting may also violate the assumption of equal detectability (Cutler and Swann 1999, Campbell et al. 2006, Roberts et al. 2006, McCoy et al. 2011). My results are in agreement with Roberts et al. (2006) who concluded that camera surveys result in significantly higher estimates of deer density than road-based sampling methods. The lack of estimated sampling variances diminish the reliability of camera survey density estimates (White 1982) and complicate method comparison. The lowest density estimate generated by cameras (8.65; August 2013) was similar to the FLIR estimate for that period, suggesting cameras may be prone to overestimating deer density. Camera surveys are capable of estimating demographic parameters both pre and post harvest, however density estimates from cameras seem to be less sensitive to seasonal changes as the difference between the pre–harvest estimate (August 2012) and the post-harvest estimate (February 2013) did not detect a reduction in the population due to harvest. Cameras accurately estimated the reduction in antlered males due to hunting; however I observed an increase in the antlerless segment of the population post–harvest that negated the reduction in antlered deer. I detected the greatest fawn recruitment in the February 2013 survey period, suggesting an underestimation of fawn recruitment during pre-harvest camera surveys. I attribute the discrepancies to weaning fawns having less interest in bait sites, resulting in a reduced fawn detection probability during the August surveys.

Given the failure to estimate sampling variance that would allow for an evaluation of accuracy, the lack of sensitivity to seasonal changes, and the underestimation of pre-harvest fawn recruitment, camera surveys over large spatial scales do not seem to warrant the high cost of equipment and labor. FLIR surveys clearly out preformed spotlight surveys but the similarity in the methods and high cost of the FLIR unit may dissuade deer managers. The increased labor and mileage costs necessary to provide sufficient precision for spotlight surveys is an important consideration; however, as cost of long term monitoring may quickly justify the initial investment in the FLIR unit. I suggest FLIR-based road transect distance sampling as a preferential technique to estimate deer population parameters at the management unit scale.

Management Implications

Management actions should always be based on the best available science. Given the failure of camera surveys to generate estimates of sampling variance and the disparate estimates of deer density, I do not recommend traditional camera surveys using the Jacobson method be utilized by state deer managers. Distance sampling via road transect surveys appeared to provide adequate estimates of deer density despite violations of study design due to non-random transects. Spotlight surveys are affordable but require substantial effort to achieve precision. Incorporating infrared technology into road surveys provided higher detection probabilities and required less effort to generate sufficient precision for management decisions, and is the recommended method to estimate deer population parameters.

Table 3.1 The top 6 models for spotlight surveys in each period, including conventional distance sampling and 5 multiple covariate distance sampling models, to estimate deer density in the Green Ridge State Forest, Maryland, USA.

Model	Parameters	AIC_c[a]	ΔAIC_c	ω[b]
August 2012				
CDS[c]		114.146	0.00	0.97
MCDS[d]	precip	121.846	7.70	0.01
	temp	124.229	10.08	0.01
	bp[e]	124.975	10.83	0.01
	precip + temp	142.119	27.97	0.00
	bp + precip	146.523	32.38	0.00
February 2013				
CDS		116.140	0.00	0.40
MCDS	temp	119.771	3.63	0.21
	precip	120.110	3.97	0.20
	bp	121.004	4.86	0.12
	wind speed	121.710	5.57	0.07
	precip + temp	168.229	52.09	0.00
August 2013				
CDS		101.700	0.00	0.93
MCDS	bp	110.134	8.42	0.04
	precip	112.393	10.69	0.01
	temp	112.651	10.95	0.01
	bp + precip	138.090	36.39	0.00
	bp + temp	139.487	37.79	0.00

a. Akaike's Information Criterion adjusted for small n
b. Akaike weight
c. Conventional Distance Sampling
d. Multiple Covariate Distance Sampling
e. Barometric pressure

Table 3.2 The top 6 models for FLIR surveys in each period, including conventional distance sampling and 5 multiple covariate distance sampling models, to estimate deer density in the Green Ridge State Forest, Maryland, USA.

Model	Parameters	AIC_c[a]	ΔAIC_c	ω[b]
August 2012				
CDS[c]		106.964	0.00	0.94
MCDS[d]	bp[e]	114.643	7.68	0.06
	temp	128.443	21.48	0.00
	bp + temp	129.606	22.64	0.00
	precip	136.991	30.03	0.00
	bp + precip + temp	158.213	51.25	0.00
February 2013				
CDS		88.213	0.00	0.86
MCDS	precip	91.067	2.85	0.13
	bp	95.811	7.60	0.01
	temp	99.075	10.86	0.00
	bp + precip	116.233	28.02	0.00
	bp + temp	125.801	37.59	0.00
August 2013				
CDS		110.600	0.00	0.92
MCDS	bp	114.775	4.18	0.03
	precip	114.822	4.22	0.03
	temp	115.809	5.21	0.02
	bp + precip	136.991	26.39	0.00
	bp + temp	158.213	47.61	0.00

a. Akaike's Information Criterion adjusted for small n
b. Akaike weight
c. Conventional Distance Sampling
d. Multiple Covariate Distance Sampling
e. Barometric pressure

Table 3.3 Density estimates and measures of precision for white-tailed deer obtained via 3 survey methods during August 2012, February 2013, and August 2013 in Green Ridge State Forest, Maryland, USA.

Survey Period	Method	Deer/Km^2(SE)	CV	95% Confidence Interval
August 2012	FLIR	6.38(1.11)	17.4%	4.29 - 9.49
	Spotlight	6.00(1.57)	26.1%	3.53 - 10.21
	Camera	12.42	n/a	n/a
February 2013	FLIR	3.33(0.94)	28.3%	1.87 - 5.90
	Spotlight	3.16(1.00)	31.7%	1.66 - 6.00
	Camera	12.03	n/a	n/a
August 2013	FLIR	8.10(1.20)	14.8%	5.98 - 11.35
	Spotlight	3.93(0.86)	22.1%	2.47 - 6.27
	Camera	8.65	n/a	n/a

Table 3.4 Estimates of adult sex ratio (does:buck) and fawn recruitment (fawns/adult doe) for white-tailed deer obtained via 3 survey methods during August 2012, February 2013, and August 2013 in Green Ridge State Forest, Maryland, USA.

Survey Period	Method	Adult Sex Ratio	Fawns / Doe
August 2012	FLIR	2.7 : 1	0.46
	Spotlight	2.0 : 1	0.38
	Camera	2.5 : 1	0.28
February 2013	FLIR [a]	n/a	n/a
	Spotlight [a]	n/a	n/a
	Camera	3.1 : 1	0.63
August 2013	FLIR	2.3 : 1	0.46
	Spotlight	2.3 : 1	0.74
	Camera	2.4 : 1	0.36

a. The use of road survey equipment proved inadequate to reliably estimate demographic parameters due to difficulty differentiating adult females, large fawns, and shed bucks.

Table 3.5 Cost breakdown per survey period for spotlight, FLIR, and camera surveys. Overall total cost, cost per survey period, and cost per survey period without equipment are included.

Expense	FLIR	Spotlight	Cameras
Equipment	$8,769.96[a]	$869.97[a]	$13,399.00[b]
Supplies	$0.00	$0.00	$616.40[c]
Field Hours[d]	$432.00	$432.00	$864.00
Analysis Hours[d]	$48.00	$48.00	$240.00
Mileage[e]	$92.00	$92.00	$192.50
Total Cost	$9,341.96	$1,441.97	$15,311.90
Survey Period[f]	$2,325.99	$745.99	$4,592.70
Survey Period w/o Equipment	$572.00	$572.00	$1,912.90

a. Fixed equipment costs for distance sampling included a 12V spotlight, binoculars, and a laser rangefinder for both methods, and a FLIR unit and monitor for FLIR surveys.
b. Fixed equipment costs for camera surveys included 20x cameras, 20x security boxes, 20x cable locks, and 40x 2GB SD memory cards.
c. Supplies for camera surveys included corn and batteries and were purchases for every period.
d. $12.00/employee/hour.
e. $0.55/mile.
f. Cost/survey period assuming a 5 year life of equipment.

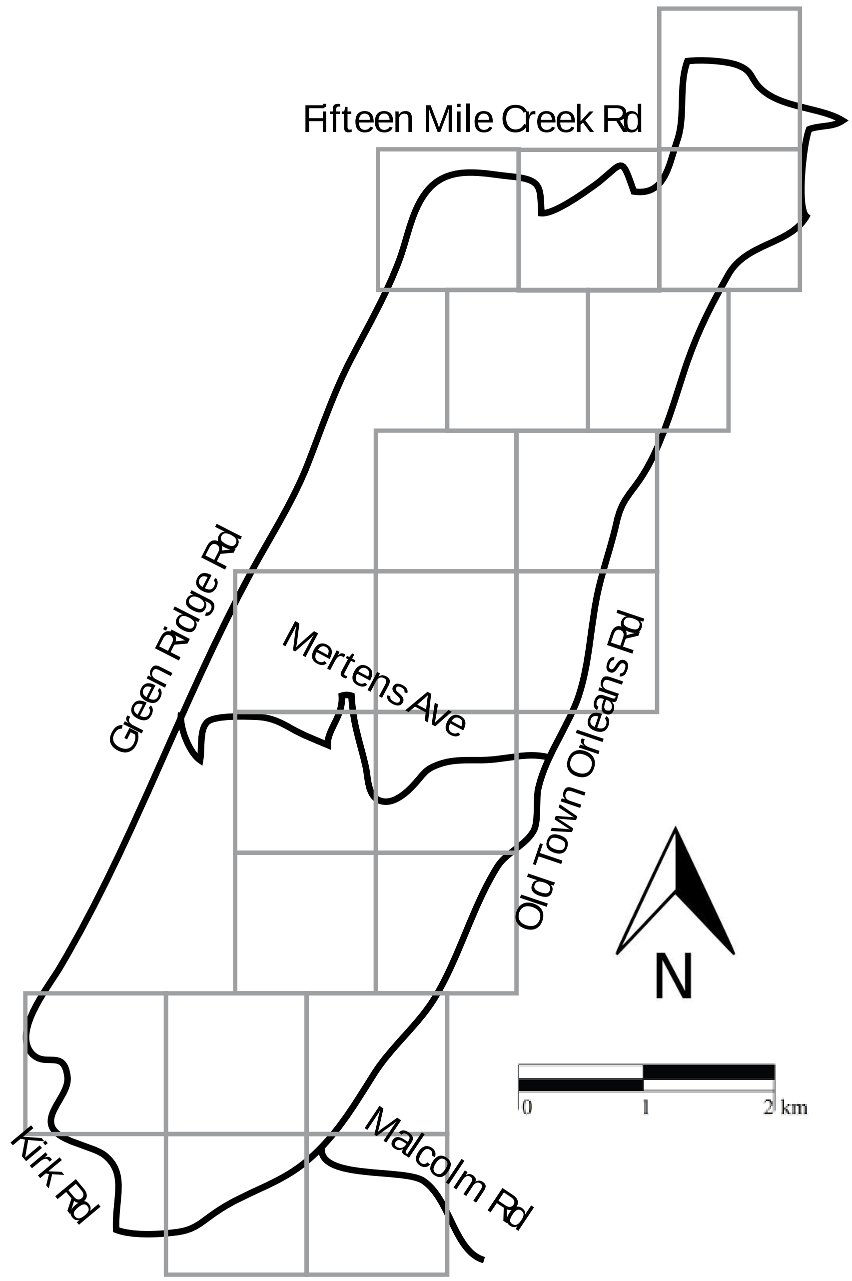

Figure 3.1 Map of the study area showing the continuous road transect used during spotlight and FLIR surveys and the 100 ha grid cells network used for camera placement. Grid cell were arranged to avoid private lands on the western portion of the study area.

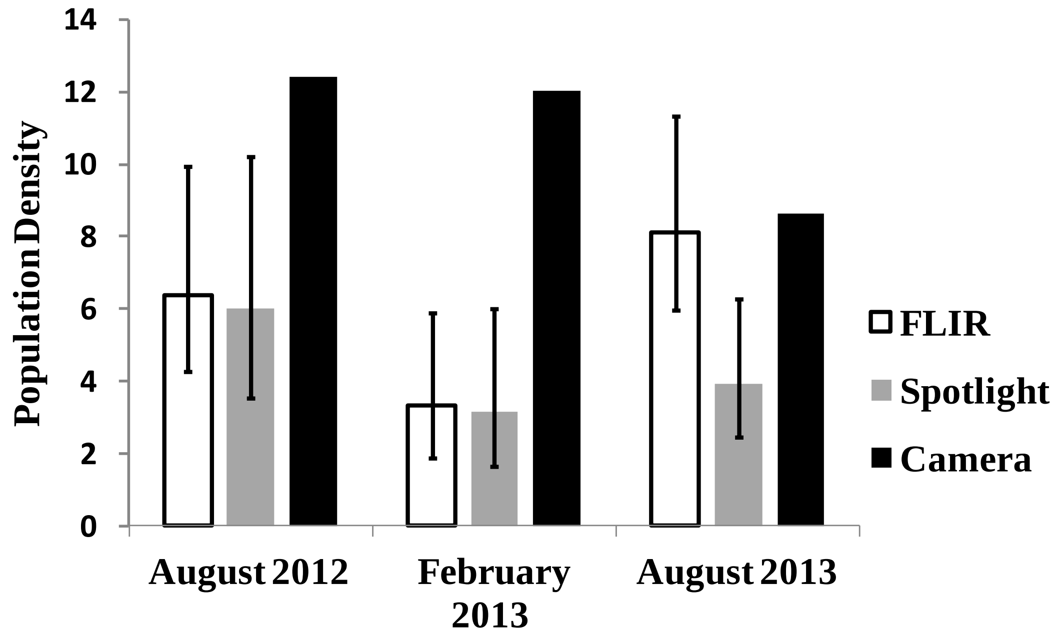

Figure 3.2 White-tailed deer density estimates (no. deer/km^2) by survey period for Green Ridge State Forest, Maryland, USA.

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