Effect of Hunter Selectivity on Harvest Rates of Radio-Collared White-Tailed Deer in Pennsylvania

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Research Article

Effect of Hunter Selectivity on Harvest Rates of Radio-Collared White-Tailed Deer in Pennsylvania

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ABSTRACT Radio transmitters are a commonly used tool for monitoring the fates of harvested species, although little research has been devoted to whether a visible radio transmitter changes a hunters' willingness to harvest that animal. We initially surveyed deer hunters to assess their willingness to harvest radio-collared deer and predicted radio collars were unlikely to affect the harvest of antlerless deer, but hunters may be less willing to harvest small-antlered males with radio collars compared to large-antlered males. We fitted white-tailed deer (*Odocoileus virginianus*) with radio collars that were visible to hunters or with ear-tag transmitters or ear-tags that were difficult to detect visually and estimated if harvest rates differed among marking methods. For females, the best model failed to detect an effect of radio collars on harvest rates. Also, we failed to detect a difference between male deer fitted with radio collars and ear-tag transmitters. When we compared males fitted with radio collars versus ear tags, we found harvest rate patterns were opposite to our predictions, with lower harvest rates for adult males fitted with radio collars and higher harvest rates for yearling males fitted with radio collars. Our study suggests that harvest rate estimates generated from a sample of deer fitted with visible radio collars can be representative of the population of inference. Published 2014. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS ear tag, harvest rate, hunter behavior, *Odocoileus virginianus*, Pennsylvania, radiocollar, white-tailed deer.

Radiotelemetry is widely used in wildlife research to estimate survival or harvest rates of hunted species. A sample of animals fitted with radio transmitters is used to make inferences about a population of interest, and for white-tailed deer (*Odocoileus virginianus*) this is usually a transmitter fitted to the animal using a neck collar. A number of assumptions about the radio-collared deer are required to make inference to the larger population (White and Garrott 1990), and 1 assumption is that the radio transmitter does not affect the characteristic being estimated (e.g., probability of survival). To date, the focus of efforts to assess the animal welfare aspect of telemetry has been to assess the effect of radio transmitters on animals (e.g., Hill and Elphick 2012) and develop designs to affix radio transmitters that minimize behavioral or physical impairment of the study animal (e.g., Diefenbach et al. 2003).

An important use of telemetry with white-tailed deer has been to estimate harvest rates (DelGiudice et al. 2002, Norton et al. 2012). Consequently, not only must radio transmitters have minimal adverse effects on the deer, but also their presence must not influence the willingness of hunters to harvest deer. For example, hunters might be less likely to harvest radio-collared deer if they believe it is illegal (Jacques et al. 2011) or that by not harvesting the animal they believe they are protecting animals being studied (F. E. Buderman, Pennsylvania State University, personal observation). Alternatively, hunters may be more likely to harvest a radio-collared deer because of the novelty, or because they believe a reward might be obtained (F. E. Buderman, personal observation).

Despite the potential for patterns of hunter selectivity to influence analyses of harvest rates, attempts to assess the effect of visible radio collars on hunter willingness to harvest deer have been limited. Fuller (1990) asked hunters if they observed the radio collar on the deer they harvested and found that 17 of 42 hunters did not observe the collar before harvesting the deer. In a study of antlered deer in Pennsylvania (Long 2005, Wallingford 2012), few hunters reported seeing the radio collar before shooting the deer (E. S. Long, Seattle Pacific University, personal observation).

Jacques et al. (2011) conducted an experiment with artificial deer and simulated hunting scenarios to ascertain

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whether hunters observed the deer and the radio collar, and questioned participants as to whether they were willing to harvest the artificial deer they observed. They reported that more experienced hunters were more likely to detect the presence of radio collars, less experienced hunters were less likely to harvest a radio-collared deer because of concerns about legality, and hunters may be more likely to forego harvest of a radio-collared antlerless deer than a large-antlered deer.

Anecdotal observations and simulated harvest situations suggest possible systematic biases in harvest rates of deer fitted with radio collars. However, whether the overall effect of the various factors that influence hunter behavior lead to a greater proportion of hunters who are more (or less) willing to harvest a radio-collared animal could be difficult to predict. The reason we question whether hunter behavior can be predicted reliably is because whether an individual hunter harvests a radio-collared deer could be situation-specific. For example, if a hunter encounters 2 antlerless deer and only 1 is radio collared, would the likelihood of harvesting the radio-collared deer be different than if the hunter only encountered a single radio-collared deer? Predicting human behavior is difficult because it is influenced by personal values and societal norms, which in turn influence behavioral intentions and actual behavior (Ajzen and Fishbein 1980, Fulton et al. 1996). Understanding hunter values and societal norms has the potential to allow managers to predict hunter behavior, but surveys or simulated situations to assess hunter behavior only reflect behavioral intentions. Consequently, field studies are needed to assess whether visible radio collars affect hunter behavior and lead to systematic biases in hunter harvest selectivity.

Our objective was to evaluate if the presence of visible radio collars resulted in different harvest rates of radio-collared deer. Initially, we conducted a mail survey of a subset of hunters who hunted on areas where radio-collared female deer were present to ascertain their willingness to harvest male and female radio-collared deer. Based on the results of the hunter survey, we predicted that 1) the presence of a radio collar on antlerless deer would have no effect on harvest rates, 2) radio-collared yearling (1.5 year old) male deer would have lower harvest rates than yearlings without radio collars, and 3) adult ($\geq$2.5 years old) male deer with radio collars would have the same harvest rates as males without radio collars or that the difference would be less than for yearling males. We tested these predictions by comparing estimates of harvest rates of radio-collared deer to deer fitted with less visible ear-tag transmitters or reward tags. We evaluated whether harvest rates differed by developing statistical models that included no collar effect, a collar effect that was common across age classes, and a collar effect that differed by age class.

STUDY AREA

Ear-Tag Transmitter Study

During 2002–2004, we captured male deer in Armstrong and Centre counties. Armstrong County was contained within

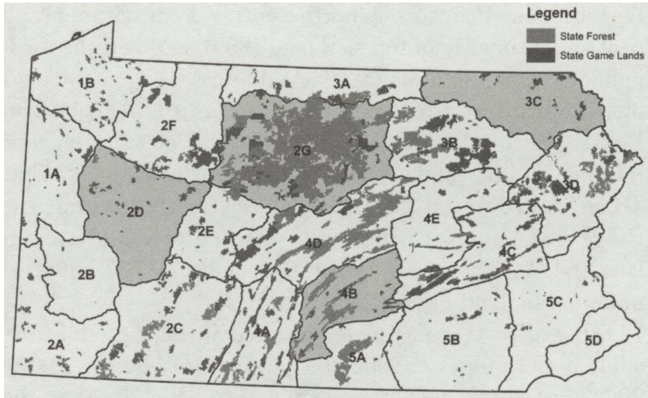

Figure 1. Map of Pennsylvania showing locations of wildlife management units (WMU) 2D, 2G, 3C, and 4B. Sproul State Forest was located in WMU 4B and Tuscarora State Forest was located in WMU 2G.

Pennsylvania Game Commission Wildlife Management Unit (WMU) 2D (Fig. 1), which was 1 of 5 WMUs in western Pennsylvania where, to be legal for harvest, antlered deer must have possessed at least 4 antler points $\geq$2.54 cm on at least 1 antler. In Armstrong County, we captured deer east of the Allegheny River in an area approximately 1,200 km^2. Armstrong County mostly consisted of privately owned land, and land use was primarily agricultural, with common crops including corn, soybeans, and grains. Forested land was composed of Appalachian oak forest (Cuff et al. 1989); however, forests were fragmented by agricultural fields and existed as isolated woodlots.

Centre County encompassed WMUs 4D and 2G (Fig. 1), which were 2 of 17 WMUs where antlered deer must have possessed $\geq$3 antler points $\geq$2.54 cm on at least 1 antler to be legally harvested. The Centre County study area encompassed parts of 2 physiographic provinces, including the Appalachian Plateau in western Centre County and the Ridge and Valley Province in central and eastern Centre County. Within this study area, we trapped deer in 3 areas, including Moshannon State Forest and State Game Lands 33 in the Appalachian Plateau region of western Centre County, State Game Lands 176 in the Ridge and Valley province of south-central Centre County, and a series of ridges and narrow valleys in eastern Centre County, within the Ridge and Valley Province. The Appalachian Plateau area was extensively forested, primarily with second- and third-growth mature hardwoods. The Ridge and Valley area consisted of a series of parallel ridges and valleys, running in a northeast-southwest orientation. Land use was primarily agricultural, including row-crops and dairy farms, but crop fields were restricted to valleys whereas long, parallel ridges were forested. Land was predominately privately owned, and deer hunting occurred throughout the area.

Reward-Tag Study

During 2009–2011, we captured male and female deer in WMUs 2D, 2G, 3C, and 4B (Fig. 1). Wildlife Management Unit 2D in western Pennsylvania was a mix of forest (59.9%) and agricultural lands (31.3%); <5% of land was public. Wildlife Management Unit 2G was located within the

Appalachian Plateau in north-central Pennsylvania and consisted primarily of forested land (88%) and had the most public land of the units (50%). Wildlife Management Unit 3C, in north-eastern Pennsylvania within the Appalachian Plateau, also was primarily forested (75.0%) but with minimal public land (2.9%). Wildlife Management Unit 4B in south-central Pennsylvania was located within the Ridge and Valley province and consisted of some forested land (64.6%) and some agricultural land (27.5%) but with more public land (15%) than WMU 2D.

Dispersal of yearling males resulted in deer establishing adult home ranges outside the capture area during 2002–2004, but most deer remained within WMUs with the same antler point restriction regulations. During 2009–2011, most yearling males established home ranges within the same WMU where captured, or at least a WMU with the same antler point restriction regulations.

METHODS

Hunter Survey

We identified all hunters who purchased a Deer Management Assistance Program (DMAP) permit to harvest antlerless deer on portions of the Sproul State Forest (WMU 2G) and Tuscarora State Forest (WMU 4B) during the 2005–2006 deer hunting season (Fig. 1). The DMAP allows landowners to identify areas where additional antlerless harvest is desired, which in this case was the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry. As part of another white-tailed deer study (Keenan 2010), we fitted female deer legal for harvest on these DMAP areas with radio collars. Hunters with WMU antlerless licenses could have harvested antlerless deer on the same areas, but we could not identify these license holders. Therefore, DMAP permit holders comprised the sampling frame of hunters who could have hunted and possessed a permit to harvest antlered and antlerless deer on these areas; we did not sub-sample DMAP permit holders.

We mailed a 2-page questionnaire in September 2006, followed by a postcard reminder after 2 weeks. We asked hunters if they observed a radio-collared deer while hunting and presented a series of statements to assess their willingness to harvest radio-collared deer. Hunters provided their level of agreement on a 5-point Likert scale from strongly agree (1) to neither agree nor disagree (3) to strongly disagree (5). Specific statements related to radiocollars included 1) I am more willing to harvest an antlerless deer when a deer is wearing a radio collar, 2) I am less willing to harvest an antlerless deer when a deer is wearing a radio collar, 3) If I saw 2 legal antlered deer, and one was wearing a radio collar, I would harvest the deer with the radio collar, 4) If I saw 2 legal antlerless deer, and one was wearing a radio collar, I would harvest the deer with the radio collar, and 5) If I saw 2 legal antlered deer, and one was wearing a radio collar, I would harvest the deer with larger antlers, regardless of whether it had a radio collar. We investigated if responses differed by age group (quartiles; 12–34, 35–46, 47–57, and >58 years old), years of experience (<3, 3–10, and >10 years), or study area using a chi-square test ($\alpha = 0.10$).

We used the results of this survey to make predictions regarding how hunter behavior might result in different harvest rates between deer with radio collars versus those with ear-tag transmitters or ear tags. We developed predictions for antlerless (female) and antlered deer separately.

Deer Capture

We captured white-tailed deer during January–April primarily using 3 techniques: modified Clover traps (Clover 1956), drop nets (Conner et al. 1987) modified for remote-release, and rocket nets (Beringer et al. 1996). In addition, during 10–12 December 2001, we used net guns from a helicopter (Hawkins and Powers Aviation, Inc., Greybull, WY; e.g., Jacques et al. 2009) in the Armstrong County study area, and in 2002 in Centre County we used dart guns (Pneu-dart, Inc., Williamsport, PA). Also, we used male deer with functional radio collars captured in an earlier study conducted in Centre County (Vreeland et al. 2004). In 2000 and 2001, these deer were caught and tagged as neonates (1–2 weeks of age) between May and June.

We handled deer captured using helicopter and Clover traps, or as neonates, without the use of sedatives. We sedated deer trapped using rocket nets and drop nets using an intra-muscular injection of xylazine hydrochloride (0.56 mg/kg body mass). We used an intra-muscular injection of yohimbine hydrochloride (0.36 mg/kg body mass) or tolazoline hydrochloride (5 mg/kg body mass) to reverse the effects of xylazine hydrochloride. We immobilized deer captured via dart guns using ketamine hydrochloride (7.5 mg/kg body mass) and xylazine hydrochloride (1.5 mg/kg body mass). Pennsylvania State University Institutional Animal Care and Use Committee approved all capture protocols (99R060, 01R135 and 34910). We classified deer as yearlings at 1 year of age (birth date = 1 June) and all deer $\geq$2 years old as adults.

Survival and Harvest Monitoring

We monitored survival of radio-marked deer on a weekly basis using ground-based telemetry via the incorporated mortality signal that was triggered when the radio transmitter did not move for $\geq$8 hours. On occasion (1–3 times per year) we used fixed-wing aircraft to locate deer from the air.

Ear-tag transmitter study.—We equipped males with 1 of 5 types of radio collars (Table 1): 245-g expandable very high frequency (VHF) neck collars with 4-cm wide belting (Model M2510B, Advanced Telemetry Systems, Inc., Isanti, MN), 700-g expandable global positioning system (GPS) collars with 5-cm wide belting (Telonics, Inc., Mesa, AZ), 1,100-g GPS collars with 5-cm wide belting (Advanced Telemetry Systems, Inc.), and 97-g expandable VHF neck collars with 3.9-cm wide belting (Model M4200, Advanced Telemetry Systems, Inc.; Diefenbach et al. 2003, Vreeland et al. 2004). All collars had brown-colored belting and black or metal transmitter casings. To monitor fates of deer not fitted with collars, we used 19-g VHF ear-tag transmitters (Advanced Telemetry Systems, Inc.; Table 1).

Table 1. Number of male deer available for harvest immediately prior to the beginning of the hunting season and fitted with very high frequency (VHF) radio collars or ear-tag transmitters and or global positioning system (GPS) radio collars, Pennsylvania, 2002–2004.

Wildlife management unit	Age	Year	Radio collar type			Ear-tag transmitter
			Fawn expandable	VHF	GPS	
2C	Adult	2004	0	24	2	28
	Yearling	2002	0	14	2	26
	Yearling	2003	0	50	3	28
	Yearling	2004	0	49	3	10
4D	Adult	2003	0	4	2	8
	Adult	2004	0	26	3	13
	Yearling	2002	5	5	2	10
	Yearling	2003	0	37	2	10
	Yearling	2004	0	42	4	6

Reward-tag study.—We fitted male and female deer with 340-g VHF radiocollars (M2510B, Advanced Telemetry Systems, Inc.), which included an expandable section for males (Table 2). The belting on these collars was 4 cm wide and brown and the transmitter was housed in black casing. To monitor harvests of deer without collars, we fitted deer with reward ear tags (Table 2). Reward tags were small ear tags designed to mimic fur coloration by placing the white stud (6383 blank white stud, Destron Fearing Du^{TM}Flex Ear-tags, National Band and Tag, Newport KY) on the inner part of the ear, and the black button back (6350 blank black button, Destron Fearing Du^{TM}Flex Ear-tags) on the outer part of the ear. Each tag was labeled as having a $100 reward, a toll free reporting number, "PA Game Commission," and a unique identification number. We used a $100 reward based on Nichols et al. (1991) who found that a reward of between $50 and $100 was needed to ensure a reporting rate of 1.0 for adult male mallards (*Anas platyrhynchos*) and Diefenbach et al. (2000) who found that rewards greater than $75 result in a reporting rate of 1.0 for ring-necked pheasants (*Phasianus colchicus*). To maximize retention of at least 1 mark until harvest, we inserted 1 reward tag in each ear. Upon harvest, the hunter called the toll free number and reported information on location of harvest, date, and sporting arm used.

Statistical Analysis

Ear-tag transmitter study.—We analyzed data from 2002–2004 using known fate models in program MARK (White and Burnham 1999) to estimate harvest rates of antlered deer by age (yearling or adult), study area (Armstrong or Centre County), radio transmitter type (collar or ear tag), and year. We estimated survival over the 14-week hunting season (Oct–Jan) for white-tailed deer in which non-hunting mortalities were right censored and harvest rate ($\hat{H}$) was estimated as the complement of the product of weekly survival (S_i) estimates ($\hat{H} = 1 - \prod S_i$). Our a priori candidate models always allowed survival rates to vary by age because antler point restriction regulations resulted in different harvest rates between yearling and adult deer. Similarly, we estimated harvest rates by study area because differences in hunter density resulted in different harvest rates (Norton et al. 2012). We developed linear models with a logit link to estimate harvest rates by year or radio transmitter type. To investigate the effect of radio transmitter type on harvest rates, we modeled a collar effect that differed by study area and age class, or differed between age classes, or as the same effect across study areas, years, and age class. All models assumed survival rates were constant over the 14-week period; we attempted to include time-dependent models (i.e., survival rates varied by week), but

Table 2. Number of male and female deer radio collared and available for harvest immediately prior to the beginning of the hunting seasons (alive and accounted for the week before the first deer season) as well as the number of deer captured in winter and fitted with ear tags in 4 wildlife management units (WMUs) in Pennsylvania, USA, 2009–2011.

	No. ear-tagged deer						No. radio-collared deer					
	Adult			Yearling			Adult			Yearling		
WMU	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011
Males												
2D	19	10	18	38	34	36	9	9	9	11	10	8
2G	10	12	19	14	11	17	18	11	7	13	15	11
3C	4	26	15	26	34	46	5	4	11	6	8	9
4B	6	12	9	43	42	36	9	9	11	8	14	13
Females												
2D	48	55	40	35	29	18	12	12	14	9	6	9
2G	46	39	39	22	21	9	55	48	18	3	0	14
3C	41	64	82	21	32	26	10	16	17	6	3	8
4B	45	51	47	50	45	30	50	26	12	2	0	15

we encountered estimability problems. We used Akaike's Information Criterion adjusted for sample size, AIC_c, to select the best model (Burnham and Anderson 2002).

Reward-tag study.—We analyzed data from 2009 to 2011 using a joint known-fate and dead-recovery model (Buderman et al. 2014). This model used survival data from deer fitted with radio transmitters to estimate the survival of ear-tagged only deer from date of tagging to the hunting season. Accounting for tagging-harvest mortality corrected for the bias that can occur with the Brownie et al. (1985) dead-recovery estimator if mortality occurs between the time of tagging and direct recoveries. Consequently, we could compare estimated harvest rates of deer fitted with radio collars to deer fitted with reward ear tags.

We fitted the joint model in program MARK using the Brownie et al. (1985) parameterization of dead recovery models. We treated monthly survival data from radio-collared deer as a separate group, coded the number of deer that survived as recoveries, and obtained survival rates by setting $S_i = 1.0$ and indirect harvest rate parameters $(f_i, i > 1) = 0$, which made the direct recovery rate parameter (f_1) equivalent to the monthly survival rate. Similarly, we estimated harvest rates of radio-collared deer by treating them as a separate group and setting $S_i = 1.0$ and indirect harvest rate parameters = 0, which made the direct recovery rate parameter (f_1) equivalent to the harvest rate (H_i).

We used the standard release-recovery data from reward ear-tagged deer to estimate harvest rates and annual survival rates. However, because we used rewards and assumed all harvested deer were reported, the recovery rate parameter (f_i) actually represented the harvest rate (H_i). In the design matrix, we coded the f_i to be a function of the harvest rate times the monthly survival rates for the period in which we captured deer to the beginning of the autumn hunting season (Oct). Because we captured deer January–April, we grouped deer by capture month so that we could model the correct number of months between capture and the hunting season (e.g., deer ear-tagged in Jan had to survive Feb–Sep). We used a log link so that monthly survival rate estimates from the radio-collared deer were multiplied by the harvest rate parameter of the reward ear-tagged deer (for direct harvest rates only) to estimate the probability that a reward-tagged deer survived the capture-harvest period and was harvested.

We conducted separate analyses for male and female deer because harvest regulations intentionally result in different harvest rates between males and females. Also, we modeled annual survival rates to vary by age, WMU, and year in all models. We developed an a priori model set in which harvest rates varied by some combination of age (yearling or adult), WMU, and year. For each of these permutations of models, we developed models in which harvest rates of ear-transmittered or radio-collared deer and ear-tagged deer did not differ, or differed by age, WMU, or both. We used Akaike's Information Criterion adjusted for small sample sizes, AIC_c, to select the best model (Burnham and Anderson 2002).

RESULTS

Hunter Survey

We mailed questionnaires to 614 hunters. Five questionnaires were undeliverable and 426 were completed for a response rate of 70%. Mean age was 45 years and most respondents (84%) had >10 years of hunting experience. Respondents demonstrated a willingness to harvest antlerless deer by purchasing an average of 1.7 WMU-specific antlerless licenses and 1.7 DMAP permits. Survey respondents experienced a WMU-specific antlerless harvest success rate of 27%, which was the same as the statewide average in 2005 (C. S. Rosenberry, Pennsylvania Game Commission, unpublished data).

We observed no differences in responses to questions among age groups or years of experience (all $P > 0.12$). More hunters in Sproul State Forest (WMU 2G) saw a radio-collared deer (10%) than in Tuscarora State Forest (WMU 4B; 3%; $P = 0.009$). Differences between study areas suggested that hunters on the Sproul State Forest were less willing to harvest a radio-collared antlerless deer; 41% versus 29% disagreed that they were more willing to harvest a radio-collared deer (statement 1 in Table 3, $P = 0.065$), 29% versus 18% agreed they were less willing to harvest a radio-collared deer (statement 2 in Table 3, $P = 0.036$), and 41%

Table 3. Responses of hunters who purchased a Deer Management Assistance Program permit to harvest antlerless deer on the Sproul (WMU 2G) and Tuscarora State Forests (WMU 4B), Pennsylvania, USA, 2006.

	Percent of respondents		
Statement	**Strongly agree or agree**	**Neither agree nor disagree**	**Strongly disagree or disagree**
1. I am more willing to harvest antlerless deer when a deer is wearing a radio collar.	9	54	37
2. I am less willing to harvest antlerless deer when a deer is wearing a radio collar.	25	47	28
3. If I saw 2 legal antlerless deer, and one was wearing a radio collar, I would harvest the deer with the radio collar.	13	49	38
4. If I saw 2 legal antlered deer, and one was wearing a radio collar, I would harvest the deer with the radio collar.	11	53	36
5. If I saw 2 legal antlered deer, and one was wearing a radio collar, I would harvest the deer with the larger antlers, regardless of whether it had a radio collar.	83	7	10

versus 32% disagreed they would harvest the radio-collared deer if they saw 2 antlerless deer (statement 3 in Table 3, $P = 0.069$). However, we present results for all hunters, regardless of age, years of experience, and study area because most hunters were uncertain of whether they would harvest an antlered or antlerless deer wearing a radio collar (Table 3). However, if 1 of the antlered deer had larger antlers, hunters indicated they would harvest this deer, regardless of the presence of a radio collar (Table 3). Also, hunters were consistent in their response to radio collars, regardless of whether the deer was antlered or antlerless: >82% of hunters responded the same way to the questions in which 2 antlered or antlerless deer were observed.

We interpreted these results to suggest that some hunters were less willing to harvest antlerless deer fitted with radio collars, but whether this would result in radio-collared deer having harvest rates unrepresentative of the population was unclear because an almost equal percentage of hunters agreed (25%) and disagreed (28%) with the statement that they were less willing to harvest an antlerless deer fitted with a radio collar (Table 3). Therefore, for antlerless deer we predicted that presence of a radio collar would have no effect on the probability a deer was harvested.

For antlered deer, we interpreted the results of the survey to suggest that the larger the antlers, the less likely a radio collar would influence their decision to harvest a deer because 83% of respondents agreed with the statement that given the choice of 2 antlered deer, they would harvest the deer with larger antlers regardless if it was wearing a radio collar. However, more hunters disagreed (38% disagreed vs. 13% agreed) with the statement that they would be more likely to harvest an antlered deer with a radio collar. Consequently, we predicted that radio collared, yearling males would have lower harvest rates than yearling males without radio collars. Furthermore, we predicted no difference in harvest rates between radio-collared adult males and those without radio collars, or that the difference would be less than for yearling males.

Male Harvest Rates

Ear-tag transmitter study.—We had sufficient data to model harvest rates for yearling deer for both study areas all 3 years, but for adult males we only had sufficient data for 2004 in Armstrong County and 2003–2004 in Centre County. The 2 models with the lowest AIC_c values did not include an effect for type of transmitter (Table 4). For the best model, harvest rates of yearling males in Armstrong County were 0.32 (SE = 0.036, 95% CI = 0.26–0.40) and in Centre County were 0.28 (SE = 0.041, 95% CI = 0.21–0.38). Harvest rates of adult males in Armstrong County were 0.47 (SE = 0.072, 95% CI = 0.35–0.64) and in Centre County were 0.50 (SE = 0.066, 95% CI = 0.38–0.65). The best model with a transmitter effect indicated that deer with radio collars were 0.95 times as likely to be harvested (95% CI = 0.66–1.37; $\beta = -0.05$, and $SE(\beta) = 0.187$), which corresponded to harvest rates of radio-collared deer to be 0.012–0.017 less than harvest rates of deer fitted with ear-tag transmitters.

Reward-tag study.—We estimated high monthly survival rates (min. = 0.9772, max. = 0.9969) for adults and yearlings during the time between capture and the beginning of the hunting seasons and detected no difference among years. Therefore, we pooled data across years and simply estimated monthly survival between capture and the hunting season for adults and yearlings to account for tagging-harvest mortality for ear-tagged deer.

The best model (AIC_c weight = 0.51) indicated the effect of a radio collar on the probability a deer was harvested differed between ages and by WMU (Table 5). The collar effect indicated radio-collared adult males were 0.78 (95% CI = 0.60–1.01; $\beta = -0.25$, $SE(\beta) = 0.132$; Table 6) times as likely to be harvested and yearling males were 1.37 times more likely to be harvested (95% CI = 0.96–1.95; $\beta = 0.32$, $SE(\beta) = 0.183$; Table 6). Estimated harvest rates of radio-collared adult male deer were 0.07–0.14 less than ear-tagged deer and estimated harvest rates of radio-collared yearling male deer were 0.04–0.09 greater than ear-tagged yearlings (Table 7).

Female Harvest Rates

We estimated high monthly survival rates (min. = 0.9781, max. = 0.9968) for adults and yearlings during the time between capture and the beginning of the hunting seasons and detected no difference among years. Therefore, we

Table 4. Model selection statistics for models of harvest rates (*H*) and collar effects (CE) of male deer fitted with radio collars or ear-tag transmitters in Armstrong and Centre counties, Pennsylvania, USA, 2002–2004. Hypothesized covariates include the age of the deer (yearling or adult), year, and county.

Model	ΔAIC_c[a]	AIC_c weights[b]	Model likelihood[c]	K[d]	$-2\log(L)$
H(age, county) CE(none)	0.00	0.31	1.00	4	1,222.4
H(age, county, year) CE(none)	0.58	0.23	0.75	9	1,213.0
H(age, county) CE	1.93	0.12	0.38	5	1,222.4
H(age, county, year) CE(age)	2.16	0.11	0.34	11	1,210.5
H(age, county, year) CE	2.46	0.09	0.29	6	1,220.9
H(age, county) CE(age)	2.58	0.09	0.28	10	1,213.0
H(age, county) CE(age, county)	4.46	0.03	0.11	8	1,218.9
H(age, county, year) CE(age, county)	6.14	0.01	0.05	13	1,210.5

[a] The difference in the value between Akaike's Information Criterion adjusted for small sample size (AIC_c) of the current model and the value for the model with the smallest AIC_c.
[b] The likelihood of the model given the data, relative to other models in the candidate set (model weights sum to 1.0).
[c] The relative likelihood of the model.
[d] The number of estimated parameters in the model.

Table 5. Model selection statistics for models of harvest rates (*H*) and collar effects (CE) for male deer fitted with radio collars or reward ear tags in wildlife management units (WMU) 2D, 2G, 3C, and 4B, Pennsylvania, USA, 2009–2011. Hypothesized covariates include the age of the deer (yearling or adult), year, and WMU.

Model	ΔAIC_c[a]	AIC_c weights[b]	Model likelihood[c]	K[d]	$-2\log(L)$
H(age, WMU) CE(age)	0.00	0.51	1.00	33	1,835.9
H(age, WMU, year) CE(age)	2.32	0.16	0.31	35	1,834.2
H(age, WMU) CE(none)	2.51	0.15	0.28	31	1,842.5
H(age, WMU) CE	3.95	0.07	0.14	32	1,841.9
H(age, WMU, year) CE(none)	5.13	0.04	0.08	33	1,841.1
H(age, WMU) CE(age, WMU)	5.23	0.04	0.07	39	1,829.0
H(age, WMU, year) CE	6.54	0.02	0.04	34	1,840.5
H(age, WMU, year) CE(age, WMU)	7.02	0.02	0.03	41	1,826.8

[a] The difference in the value between Akaike's Information Criterion adjusted for small sample size (AIC_c) of the current model and the value for the model with the smallest AIC_c.
[b] The likelihood of the model given the data, relative to other models in the candidate set (model weights sum to 1.0).
[c] The relative likelihood of the model.
[d] The number of estimated parameters in the model.

Table 6. Log link function parameter estimates for monthly survival rates and harvest rates of yearling (1.5 years old) and adult (≥2.5 years old) male deer fitted with reward ear-tags or radio collars in wildlife management units (WMU) 2D, 2G, 3C, and 4B (reference value), Pennsylvania, USA, 2009–2011.

Variable	Estimate	SE	95% CI
Intercept harvest rate	−1.458	0.128	−1.709 – −1.207
Age effect harvest rate	1.007	0.130	0.751 – 1.262
WMU 2D harvest rate	0.001	0.122	−0.237 – 0.240
WMU 2G harvest rate	−0.710	0.172	−1.046 – −0.373
WMU 3C harvest rate	−0.166	0.139	−0.437 – 0.106
Feb survival rate - adults	−0.013	0.005	−0.023 – −0.002
Mar survival rate - adults	−0.012	0.005	−0.021 – −0.002
Apr survival rate - adults	−0.022	0.007	−0.034 – −0.008
May survival rate - adults	−0.008	0.004	−0.016 – −0.001
Jun survival rate - adults	−0.011	0.004	−0.018 – −0.002
Jul survival rate - adults	−0.006	0.003	−0.012 – −0.001
Aug survival rate - adults	−0.003	0.002	−0.007 – 0.001
Sep survival rate - adults	−0.011	0.004	−0.019 – −0.002
Feb survival rate - yearlings	−0.007	0.007	−0.021 – 0.007
Mar survival rate - yearlings	−0.022	0.010	−0.040 – −0.002
Apr survival rate - yearlings	−0.022	0.010	−0.041 – −0.002
May survival rate - yearlings	−0.023	0.010	−0.043 – −0.002
Collar effect for adults	−0.250	0.132	−0.508 – 0.008
Collar effect for yearlings	0.312	0.183	−0.045 – 0.670

pooled data across years and simply estimated monthly survival between capture and the hunting season for adults and yearlings to account for tagging-harvest mortality for ear-tagged deer.

The best model (AIC_c weight = 0.45) indicated no effect of a radio collar on the probability a deer was harvested and that harvest rates varied by WMU (Table 8). Harvest rates among the 4 WMUs ranged from 0.11–0.14. The best model that included a collar effect (AIC_c weight = 0.22) indicated that radio-collared females were 1.14 (95% CI = 0.82–1.57 $\beta = 0.13$, $SE(\beta) = 0.165$; Table 9) times more likely to be harvested. For the best model with a collar effect, we estimated harvest rates of radio-collared female deer were 0.016–0.019 greater than ear-tagged deer.

DISCUSSION

We concluded our data provided limited support for the hypothesis that the presence of a radio collar on a deer causes a systematic bias in harvest rate estimates because of hunter selectivity. We failed to detect a difference for males

Table 7. Harvest rates ($\hat{H}$) of yearling (1.5 years old) and adult (≥2.5 years old) male deer fitted with reward ear-tags or radio collars and difference in harvest rates ($\hat{H}_{collar} - \hat{H}_{ear}$), Pennsylvania, USA, 2009–2011.

	Adults					Yearlings				
WMU[a]	$\hat{H}_{ear}$	SE $\hat{H}_{ear}$	$\hat{H}_{collar}$	SE $\hat{H}_{collar}$	$\hat{H}_{collar} - \hat{H}_{ear}$	$\hat{H}_{ear}$	SE $\hat{H}_{ear}$	$\hat{H}_{collar}$	SE $\hat{H}_{collar}$	$\hat{H}_{collar} - \hat{H}_{ear}$
2D	0.638	0.062	0.497	0.064	−0.14	0.233	0.030	0.318	0.052	0.085
2G	0.313	0.048	0.244	0.043	−0.07	0.114	0.021	0.156	0.031	0.042
3C	0.540	0.065	0.420	0.062	−0.12	0.197	0.027	0.269	0.048	0.072
4B	0.637	0.069	0.496	0.064	−0.14	0.233	0.030	0.318	0.052	0.085

[a] WMU, Wildlife management unit.

Table 8. Model selection statistics for models of harvest rates (*H*) and collar effects (CE) for female deer in wildlife management units (WMU) 2D, 2G, 3C, and 4B, Pennsylvania, USA, 2009–2011. Hypothesized covariates include the age of the deer (yearling or adult), year, and WMU.

Model	ΔAIC_c[a]	AIC_c weight[b]	Model Likelihood[c]	K[d]	−2log(L)
H(WMU) CE(none)	0.00	0.45	1.00	32	2,062.9
H(WMU) CE	1.41	0.22	0.49	33	2,062.3
H(age, WMU) CE(none)	2.00	0.16	0.37	33	2,062.9
H(age, WMU) CE	3.43	0.08	0.18	34	2,062.3
H(age, WMU) CE(age)	4.91	0.04	0.09	35	2,061.8
H(age, year, WMU) CE(none)	5.48	0.03	0.06	35	2,062.3
H(age, year, WMU) CE	7.02	0.01	0.03	36	2,061.8
H(age, year, WMU) CE(age)	8.38	0.01	0.02	37	2,061.2
H(age, WMU) CE(age, WMU)	15.51	0.00	0.00	41	2,060.2
H(age, year, WMU) CE(age, WMU)	16.63	0.00	0.00	43	2,057.3

[a] The difference in the value between Akaike's Information Criterion adjusted for small sample size (AIC_c) of the current model and the value for the model with the smallest AIC_c.
[b] The likelihood of the model given the data, relative to other models in the candidate set (model weights sum to 1.0).
[c] The relative likelihood of the model.
[d] The number of estimated parameters in the model.

during 2002–2004 and females during 2009–2011, and the differences we detected for yearling and adult males during 2009–2011 were opposite of what we predicted and as was indicated by Jacques et al. (2011). Although the estimated differences for these male harvest rates were large enough to have management implications (Table 7), we cannot explain why radio-collared adult males would be less likely to be harvested when our survey of hunters suggested that the presence of a radio collar would be less likely to affect their decision to harvest a large-antlered deer. Most adult male deer in Pennsylvania have ≥3 antler points on 1 side and in Armstrong County most have ≥4 antler points on 1 side (Wallingford 2012). Similarly, Jacques et al. (2011) suggested that hunters were less likely to be influenced by the presence of a radio collar on large-antlered deer.

One possibility of why we failed to detect an effect is that our sample sizes were too small to detect meaningful differences. However, estimates of the coefficient of variation for all harvest rates ranged from 10–19%, which encompasses the level of precision that is recommended for wildlife management decisions (≤12.8%; Robson and Regier 1964, Skalski and Millspaugh 2002). Furthermore, our model selection criterion supported the no collar effect hypothesis for females and the 2002–2004 male study, and the best models with a collar effect indicated a minimal difference in harvest rates.

Despite finding only limited evidence for an effect of a radio collar on harvest rates, we believe the presence of a radio collar may influence whether some hunters decide to harvest a deer. Furthermore, we agree with Jacques et al. (2011) that hunter behavior is likely heterogeneous and, depending on the hunter, could be manifested as either an increased or reduced likelihood of harvesting a radio-collared deer. For example, in our survey of hunters, a nearly equal percentage of hunters agreed and disagreed with the statement that they were less willing to harvest an antlerless deer with a radio collar (Table 3) and could explain why we found no effect of collars on female harvest rates.

The cognitive hierarchical approach to examining human behavior suggests that values, norms, and attitudes influence

Table 9. Log link function parameter estimates for survival and harvest rates female deer and monthly tagging-harvest survival rates of yearling (1.5 years old) and adult (≥2.5 years old) female deer fitted with ear tags or radio collars in wildlife management units (WMU) 2D, 2G, 3C, and 4B (reference value) Pennsylvania, USA, 2009–2011.

Variable	Estimate	SE	95% CI
Intercept harvest rate	−2.022	0.134	−2.285 – −1.758
WMU 2D harvest rate	0.043	0.200	−0.349 – 0.436
WMU 2G harvest rate	−0.162	0.209	−0.572 – 0.247
WMU 3C harvest rate	−0.139	0.206	−0.542 – 0.265
Feb survival rate - adults	−0.013	0.005	−0.023 – −0.003
Mar survival rate - adults	−0.012	0.005	−0.021 – −0.002
Apr survival rate - adults	−0.022	0.007	−0.035 – 0.009
May survival rate - adults	−0.008	0.004	−0.016 – 0.001
Jun survival rate - adults	−0.011	0.004	−0.018 – -0.003
Jul survival rate - adults	−0.006	0.003	−0.012 – −0.001
Aug survival rate - adults	−0.003	0.002	−0.007 – 0.001
Sep survival rate - adults	−0.011	0.004	−0.019 – −0.003
Feb survival rate - yearlings	−0.008	0.008	−0.023 – 0.008
Mar survival rate - yearlings	−0.022	0.010	−0.042 – −0.003
Apr survival rate - yearlings	−0.022	0.010	−0.041 – −0.003
May survival rate - yearlings	−0.023	0.010	−0.044 – −0.003

behavioral intentions and can be used to predict human behavior (Fulton et al. 1996). The cognitive hierarchical approach has been successful in explaining human behavior (Ajzen and Fishbein 1980), but researchers recognize that behavioral intentions may be specific to situations. Furthermore, even though a person may be able to describe what action they intend to take in a given situation, behavioral intention may be a poor predictor of actual behavior (e.g., Loomis et al. 1996). The survey of hunters that we conducted, and the simulated hunting experiment conducted by Jacques et al. (2011), only assessed hunter intentions and may have limited value in predicting the willingness of hunters to harvest radio-collared deer in actual hunting situations.

We can envision numerous situation-specific scenarios that might lead a hunter with a given behavioral intention to result in different actions. For example, if a hunter has the opportunity to harvest a radio-collared deer at the beginning of a hunt they may be less likely to harvest the deer than if the radio-collared deer is the first deer encountered after many hours of hunting. Similarly, willingness to harvest a radio-collared deer may be greater for large-antlered deer than antlerless deer (Jacques et al. 2011). Our survey of hunters suggested that willingness to harvest a radio-collared deer changed if a non-collared deer was present (Table 3). However, in 4 of 5 statements (Table 3), nearly half or more of the hunters were uncertain of their actions in relation to a radio-collared deer and only in the large-antlered deer scenario (statement 5) were most hunters certain of their action. This uncertainty and the effect of large antlers on hunter behavior suggest that once a deer is radio collared, researchers have no way of knowing or predicting the exact situation (e.g., no. deer present, size of antlers) when that particular deer may be seen by a hunter.

Similarly, we would expect individual hunters to vary in their willingness to harvest a radio-collared deer depending on deer density (i.e., perceived or real opportunity to harvest a deer) and hunter density (i.e., perceived or real competition to harvesting a deer). Pennsylvania hunters have indicated a greater willingness to harvest antlerless deer when they observe a lot of deer while hunting (C. S. Rosenberry, unpublished data). Because of the large number of potential scenarios to which hunters could be exposed when making a decision about whether to harvest a radio-collared deer, we doubt hunter actions can be predicted reliably based on assessments of behavioral intentions. Even with the simplest scenarios (e.g., ballot initiatives; Manfredo et al. 1997), predictive models of behavior based on cognitive theory rarely have better than 70% accuracy (D. C. Fulton, U.S. Geological Survey, personal communication).

We are encouraged that we failed to detect an effect of collars on harvest rates, because collars are the preferred method to attach transmitters to deer. Collars can accommodate larger batteries (longer operational life and greater electrical power) and they are easier to attach, or have greater retention rates, than other methods (e.g., ear tags and surgical implantation of transmitters). However, we believe additional field studies are warranted that assess whether harvest rates for radio-collared deer differ from non-collared deer and if those differences could affect population-level inferences. The technology is available, and statistical methods have been developed (e.g., Buderman et al. 2014), to determine if a radio-collared sample of deer is unrepresentative of the deer population because of hunter harvest selectivity. If consistent biases exist in harvest rates of radio-collared deer, then we believe more research on hunter attitudes and opinions is needed to provide insights into the factors that form hunters' behavioral intentions and allow researchers to develop testable predictions from models of hunter behavior.

MANAGEMENT IMPLICATIONS

Wildlife managers often prefer radio collars to smaller transmitters (e.g., ear-tag transmitters), because of longer battery life and larger power supply, facilitating data transmission over greater distances. However, if the harvest rate of radio-collared animals is not representive of the population of inference, harvest rate estimators may be biased. Our research in Pennsylvania indicates that hunters do not systematically select for or against radio-collared deer; thus, managers are likely to obtain accurate estimates of harvest rate using a radio-collared sample of deer. If concern remains that a visible transmitter may affect whether a hunter decides to harvest a deer, then methods are available to incorporate an evaluation of whether hunter harvest selectivity introduces a systematic bias in harvest rate estimates.

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