REPORTING-RATE VARIABILITY AND PRECISION OF WHITE-TAILED DEER HARVEST ESTIMATES IN PENNSYLVANIA

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Abstract: Use of reported harvests as an index to actual harvest assumes that the proportion of harvest reported is equal for all types of animals and hunters and does not vary spatially or temporally. We modeled reporting rates of white-tailed deer (*Odocoileus virginianus*) harvest to determine whether they varied by year, deer management unit (DMU), type of deer (antlered or antlerless), or sex. During rifle seasons in Pennsylvania, USA, from 1990 to 2001, reporting rates varied by year, DMU, and type of deer (antlered or antlerless). Harvest estimates of antlered and antlerless deer were precise for both statewide (CV < 2.5%) and DMUs (CV < 24%, median CV < 5.2%). For DMUs, reported harvests were poor predictors of estimated antlered harvests (median R^2 = 0.287) but generally acceptable for antlerless harvests (median R^2 = 0.909). During the 2000 and 2001 hunting seasons, statewide average predicted reporting rates ranged from 36 to 60% and varied by year, hunting season, and type of deer. Average predicted reporting rates also varied by DMU (range = 31.5–57.5%). Applying rifle-season reporting rates to other seasons resulted in overestimating harvest by 26–28%. Variability of reporting rates precluded use of reported harvests as reliable indices of actual harvest. We recommend regular estimation of reporting rates and caution against assuming a constant reporting rate, even in consistent harvest registration systems.

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Reliable harvest estimates are an essential component of management programs for harvested populations (Roseberry and Wolff 1991). In addition, harvest data may be used to assess population response to ecological factors such as weather (Marshal et al. 2002), predation (Mech and Nelson 2000), and population density (McCullough 2001, Jenks et al. 2002).

Management programs often use harvest registration systems, such as check stations and report cards, to monitor harvests and make management decisions (Rupp et al. 2000). However, not all successful hunters comply with registration requirements, even when mandatory (Strickland et al. 1994, Rupp et al. 2000). As a result, counts from harvest registration provide a minimum count (Strickland et al. 1994, Unsworth et al. 2002) and may be a poor index to total harvests (Unsworth et al. 2002).

For reported harvests to serve as an index to actual harvest, detection probability (or reporting rate) must remain constant (Lancia et al. 1994). Alternatively, reported harvest can be adjusted by reporting rate to obtain an estimate of the harvest. In some situations, reporting rate is difficult or impossible to estimate (Strickland et al. 1994, Rupp et al. 2000), and managers may resort to assumptions regarding reporting-rate consistency (Rupp et al. 2000).

Reporting-rate inconsistency can cause errors in harvest estimates, and consideration of this source of error has been encouraged (Roseberry and Wolff 1991, Skalski and Millspaugh 2002). However, evaluation of reporting-rate variability rarely occurs. In a recent survey of state wildlife agencies (Rupp et al. 2000), 9 agencies used report cards to monitor deer harvests, and 6 reported adjusting report-card counts with estimates of reporting rates to obtain a harvest estimate (Rupp et al. 2000). One agency assumed that the reporting rate for report cards was 100%. Similarly, 27 agencies used check-station data to estimate deer harvest, but few reported adjustments to reported harvests (Rupp et al. 2000). One agency calculated reporting rates from a mail survey and another assumed a constant reporting rate (Rupp et al. 2000). Untested assumptions and failure to account for reporting-rate variability may render harvest information unsuitable for management and research purposes.

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Since 1982, the Pennsylvania Game Commission (PGC) has used a report-card registration system for hunters to report the harvest of each white-tailed deer and determined whether field-checked harvested deer were reported to estimate annual reporting rates by type of deer (antlered vs. antlerless) and deer DMU. Reporting rates are used to adjust report-card counts to estimate harvest by DMU for antlered and antlerless deer. Traditionally, the PGC has only field-checked harvested deer during the regular rifle seasons when most deer are harvested (PGC, unpublished data) and has used these reporting rates to estimate harvest in all other seasons (e.g., early and late archery and muzzleloader seasons).

We analyzed 12 years of data (1990–2001) collected from white-tailed deer harvested in Pennsylvania to investigate reporting-rate variability and precision of harvest estimates. We determined whether reporting rates varied temporally, spatially, by type of deer (antlered and antlerless), and by sex. Also, for 2 years (2000–2001) data were available to investigate differences in reporting rates between 2 different hunting seasons. We used reported harvest and reporting rates to estimate size and precision of harvest estimates and evaluate assumptions that reporting rates do not vary temporally, spatially, by type of deer, or by season.

METHODS

Pennsylvania Game Commission Harvest Registration System

A general hunting license permits hunters to harvest 1 antlered deer during any season, or an antlerless deer during a flintlock-only season if they did not previously harvest an antlered deer. An allocation of DMU-specific antlerless licenses is issued on a first-come, first-served basis. During our study, we defined an antlered deer as having ≥1 antler with ≥2 points or >8 cm (3 in) in length. All hunters were provided 2 postage-paid postcards with their general hunting license that could be used to report harvest of deer and turkeys (*Meleagris gallopavo*), and a postage-paid postcard accompanied each antlerless license. Hunters were required to report harvest of each deer within 10 days. Information collected on report cards varied slightly over the years, but county of harvest, type of deer (antlered or antlerless), and date of harvest were obtained.

To assess hunter cooperation with reporting harvest of a deer, PGC personnel visited meat processors and hunting camps across the state each year during the 12–15-day antlered and antlerless firearms seasons (hereafter, rifle season). Personnel recorded hunter license numbers and the following information regarding each harvested deer: county where harvested, age, sex, and other physical characteristics (e.g., antler points). This database of field-checked deer harvested by hunters was then cross-tabulated with the database of report cards received by the agency to determine which field-checked deer were reported as harvested via the report-card system.

Although successful hunters during all deer seasons were mandated to return report cards, we only analyzed report-card data for hunting seasons when field-checks occurred. Data on harvested deer recorded in the presence of the hunter who harvested the deer were not used to estimate reporting rate.

During 1990–1999, harvested deer were field-checked by PGC personnel only during the regular rifle season for antlered and antlerless deer. During 2000 and 2001, PGC personnel also field-checked harvested deer in October, which provided reporting information for archery hunters (Oct–mid-Nov season) and hunters who participated in a special statewide 3–7 day antlerless hunt (muzzleloader, senior [>64 yr old], and youth [12–16 yr old] hunters) in mid-October. Hereafter, we refer to these archery and special antlerless harvests as the October season.

Reporting-rate Estimation

We estimated reporting rates for the 2000–2001 hunting seasons and investigated whether reporting rates varied according to year of harvest (YEAR), season (SEASON; Oct or rifle), type of deer (ANTLER; antlered or antlerless), sex (SEX), and DMU (DMU; group of ≥1 county). For the period of 1990–2001, we evaluated (only for the rifle season) whether reporting rates varied according to YEAR, ANTLER, SEX, and DMU.

We estimated probability of a hunter reporting the harvest of a deer using standard logistic regression for a binary-dependent variable (PROC LOGISTIC; SAS Institute 2000). For each harvested deer checked by PGC personnel in a given year, we recorded whether the deer was reported (1 = reported, 0 = not reported). We excluded data from field-checked deer in which the DMU where harvested was unknown because only 23 field-checked deer were of unknown DMU and <400 report cards of >200,000 received per year by the PGC were of unknown DMU.

We treated independent variables as categorical in the logistic regression analysis: YEAR (2000 and 2001 or 1990–2001), SEX, SEASON, ANTLER, and DMU where killed (31 units). All variables, including the interaction terms of YEAR × ANTLER, YEAR × DMU, YEAR × SEX, and ANTLER × DMU, were selected prior to the analysis because reporting rates were known to vary by year, type of deer, and DMU. When analyzing the 1990–2001 data, we included the additional interaction term YEAR × ANTLER × DMU.

We used Akaike's Information Criterion (AIC) to select the most parsimonious model of independent variables for estimating harvest probability (Burnham and Anderson 1998). We used the Hosmer-Lemeshow goodness-of-fit (GOF) statistic (Hosmer and Lemeshow 2000) to assess model fit for the full model (i.e., all variables and interaction terms). We fitted a series of reduced models by eliminating variables (and any associated interaction terms) using a backward-selection process that eliminated variables producing the largest decrease in AIC. However, we always included YEAR and ANTLER in models because reporting rates were known to differ between antlered and antlerless deer (PGC, unpublished data). Although this approach does not strictly adhere to the protocol proposed by Burnham and Anderson (1998) of a priori specification of all candidate models, we believe it does provide a reasonable set of candidate models from the potential large number of subset models that could be defined from the combinations of variables and interactions that were chosen a priori.

We estimated harvest (H) using a modified Horvitz-Thompson (H-T) estimator

$$\hat{H}_k = \sum_{i=1}^{h_k} \frac{1}{\hat{p}(\underline{z}_i \mid \hat{\underline{\theta}})},$$

where h_k = the number of report cards received by the PGC in year k, $\underline{z}_i$ is the vector of indicator variables for report card i, and $\hat{\underline{\theta}}$ is the vector of estimated coefficients, $\hat{\theta}_0, \hat{\theta}_1, ..., \hat{\theta}_n$. We estimated the probability of reporting a harvested deer, $\hat{p}(\underline{z}_i \mid \hat{\underline{\theta}})$ via a logit link function:

$$\hat{p}(\underline{z}_i \mid \hat{\underline{\theta}}) = \frac{\exp\left\{\hat{\theta}_0 + \hat{\theta}_1 z_{1i} + \hat{\theta}_2 z_{2i} + \cdots + \hat{\theta}_n z_{ni}\right\}}{1 + \exp\left\{\hat{\theta}_0 + \hat{\theta}_1 z_{1i} + \hat{\theta}_2 z_{2i} + \cdots + \hat{\theta}_n z_{ni}\right\}}. \quad (1)$$

We estimated the variance of $\hat{H}_k$ as the sum of the H-T sampling variance and the sampling variance associated with the model of detection probabilities:

$$\hat{\text{v}}\text{ar}(\hat{H}_k) = \sum_{i=1}^{h_k} \left(\frac{1 - \hat{p}(\underline{z}_i \mid \hat{\underline{\theta}})}{\hat{p}(\underline{z}_i \mid \hat{\underline{\theta}})} \right) + D(\hat{\underline{\theta}})' \hat{I}(\hat{\underline{\theta}}) D(\hat{\underline{\theta}}),$$

where $D(\hat{\underline{\theta}})$ is the column-vector sum of partial derivatives of $1/\hat{p}(\underline{z}_i \mid \hat{\underline{\theta}})$ for all reported harvests in year k, and $\hat{I}(\hat{\underline{\theta}})$ is the estimated variance–covariance matrix for the coefficients in the linear-logistic model (Borchers et al. 1998). We assumed that $\hat{H}$ was distributed log normally (Chao 1989) and thus calculated the 95% confidence limits as

$$95\% \text{ CI} = \hat{H}_k / C, \hat{H}_k \times C,$$

where C was calculated as:

$$C = \exp\left\{1.96\sqrt{\ln\left(1 + \frac{\hat{\text{v}}\text{ar}(\hat{H}_k)}{(\hat{H}_k)^2}\right)}\right\}.$$

We estimated H for each year by season and type of deer. In addition, for 2000–2001 data, we applied reporting rates for the rifle season to estimate the October harvest so that we could assess the bias introduced by applying reporting rates from the rifle season to other hunting seasons. To assess the ability of report-card counts to index harvest, we used the 1990–2001 harvest estimates by DMU to model the relationship between reported and estimated harvest as linear (PROC REG; SAS Institute 2000).

RESULTS

During the 2000 and 2001 hunting seasons, PGC personnel checked 93,758 harvested deer that could be cross-tabulated with report cards (n = 53,289) received from hunters to determine whether each harvested deer was reported to the PGC. The linear-logistic model of reporting rates containing all variables and interaction terms fit the data ($\chi^2_8 = 5.22$, $P = 0.734$). We found that the best model included all variables except SEX and its corresponding interaction term (SEX × YEAR; Tables 1, 2).

For both years, average predicted reporting rate was greater for hunters who harvested antlerless than antlered deer during both October and rifle seasons. Average predicted reporting rates ranged from 36 to 60% among hunting seasons, type of deer, and years (Table 3). These reporting

Table 1. Linear-logistic models compared using Akaike's Information Criteria (AIC) to estimate the probability of hunters reporting harvest of white-tailed deer, number of parameters (k), and ΔAIC values, Pennsylvania, USA, 2000–2001. The full model (k = 99, n = 93,758) contained the following variables: year of harvest (YEAR), sex (SEX), season killed (SEASON), type of deer (ANTLER), deer management unit where killed (DMU), and interaction terms (YEAR × ANTLER, YEAR × DMU, YEAR × SEX, ANTLER × DMU, SEASON × ANTLER).

Model variables	k	ΔAIC
YEAR, SEASON, ANTLER, DMU, YEAR × ANTLER, YEAR × DMU, ANTLER × DMU, SEASON × ANTLER	95	0.00
YEAR, SEX, SEASON, ANTLER, DMU, YEAR × ANTLER, YEAR × DMU, YEAR × SEX, ANTLER × DMU, SEASON × ANTLER	99	2.67
YEAR, SEX, SEASON, ANTLER, DMU	35	60.31
YEAR, ANTLER, DMU, YEAR × ANTLER, YEAR × DMU, ANTLER × DMU	94	199.29
YEAR, SEX, ANTLER, DMU, YEAR × ANTLER, YEAR × DMU, YEAR × SEX, ANTLER × DMU	96	213.82
YEAR, SEASON, ANTLER, YEAR × ANTLER, SEASON × ANTLER	6	628.32
YEAR, SEX, SEASON, ANTLER, YEAR × ANTLER, SEASON × SEX, SEASON × ANTLER, YEAR × SEX	9	633.60
YEAR, ANTLER, YEAR × ANTLER	3	855.00
YEAR, SEX, ANTLER, YEAR × ANTLER, YEAR × SEX	6	858.68

rates also differed among DMUs (range = 31.5–57.5%; Fig. 1). Although a model that included sex of the deer was competitive (ΔAIC = 2.67), reporting rates for female antlerless deer were only slightly greater than for male antlerless deer (0.1–1.3%) and resulted in little change in total estimated harvest.

If reporting rates from rifle season were applied to report cards for deer harvested during October–mid-November, October harvest was overestimated by 19,330–20,573 deer (26–28%; Table 4). However, because October harvest was a relatively small proportion of total harvest, resulting relative bias in total harvest was 4%.

During rifle seasons of 1990–2001, PGC personnel field-checked 497,545 harvested deer that could be cross-tabulated with report cards (n = 281,820) received from hunters to determine whether each harvested deer was reported to the PGC. We found that reporting

Table 2. Maximum-likelihood estimates of parameters in the linear-logistic model to estimate the probability of hunters reporting the harvest of white-tailed deer, Pennsylvania, USA, 2000–2001. All variables were categorical and estimated via a design matrix in which 1 level was the reference value to all other levels (e.g., the reference value for SEX was male, so the coefficient is included only if the sex were female). Variables in the model were YEAR (reference year = 2001), SEASON (reference season = rifle), ANTLER (reference = antlerless deer), DMU (deer management unit; reference DMU = 31), and interaction terms YEAR × ANTLER, YEAR × DMU, ANTLER × DMU, and SEASON × ANTLER.

Parameter (level)	Estimate	SE	Wald χ^2_1	P
Intercept	–0.6807	0.177	14.84	<0.001
YEAR (2000)	–0.2651	0.157	2.86	0.091
SEASON (Oct)	0.3997	0.213	3.51	0.061
ANTLER (antlered)	0.2834	0.189	2.25	0.134
DMU (DMU 1)	0.2499	0.182	1.88	0.170
DMU (DMU 2)	0.3186	0.187	2.91	0.088
DMU (DMU 3)	0.2014	0.195	1.07	0.302
DMU (DMU 4)	0.6264	0.193	10.49	0.001
DMU (DMU 5)	0.4687	0.189	6.16	0.013
DMU (DMU 6)	0.2011	0.193	1.09	0.297
DMU (DMU 7)	0.2777	0.186	2.22	0.136
DMU (DMU 8)	0.3733	0.202	3.43	0.064
DMU (DMU 9)	0.2260	0.223	1.03	0.310
DMU (DMU 10)	0.5388	0.186	8.41	0.004
DMU (DMU 11)	0.3682	0.182	4.09	0.043
DMU (DMU 12)	0.5034	0.194	6.77	0.009
DMU (DMU 13)	0.1584	0.185	0.73	0.393
DMU (DMU 14)	0.1216	0.192	0.40	0.527
DMU (DMU 15)	0.3331	0.188	3.14	0.077
DMU (DMU 16)	0.4803	0.198	5.92	0.015
DMU (DMU 17)	0.6604	0.194	11.59	0.001
DMU (DMU 18)	0.6082	0.198	9.42	0.002
DMU (DMU 19)	0.7691	0.187	16.88	<0.001
DMU (DMU 20)	0.1040	0.187	0.31	0.578
DMU (DMU 21)	0.3733	0.183	4.14	0.042
DMU (DMU 22)	0.2912	0.189	2.38	0.123
DMU (DMU 23)	0.6671	0.194	11.77	0.001
DMU (DMU 24)	0.6218	0.189	10.80	0.001
DMU (DMU 25)	0.5132	0.191	7.19	0.007
DMU (DMU 26)	–0.0149	0.230	0.01	0.948
DMU (DMU 27)	0.3132	0.194	2.60	0.107
DMU (DMU 28)	0.3436	0.190	3.28	0.070
DMU (DMU 29)	0.2543	0.207	1.51	0.219
DMU (DMU 30)	0.1698	0.202	0.71	0.401
SEASON (Oct) × ANTLER (antlered)	0.1299	0.217	0.36	0.549

(continued on next page)

Table 2. continued.

Parameter (level)	Estimate	SE	Wald χ^2_1	*P*
YEAR (2000) × ANTLER (antlered)	0.2206	0.028	64.52	<0.001
ANTLER (antlered) × DMU (DMU 1)	–0.2124	0.194	1.19	0.274
ANTLER (antlered) × DMU (DMU 2)	–0.2863	0.200	2.06	0.152
ANTLER (antlered) × DMU (DMU 3)	–0.1737	0.210	0.68	0.408
ANTLER (antlered) × DMU (DMU 4)	–0.1831	0.208	0.78	0.378
ANTLER (antlered) × DMU (DMU 5)	–0.2631	0.203	1.68	0.195
ANTLER (antlered) × DMU (DMU 6)	–0.0481	0.207	0.05	0.816
ANTLER (antlered) × DMU (DMU 7)	–0.1808	0.200	0.82	0.365
ANTLER (antlered) × DMU (DMU 8)	–0.1837	0.214	0.74	0.391
ANTLER (antlered) × DMU (DMU 9)	–0.2390	0.245	0.95	0.330
ANTLER (antlered) × DMU (DMU 10)	–0.2478	0.200	1.54	0.215
ANTLER (antlered) × DMU (DMU 11)	–0.0581	0.195	0.09	0.766
ANTLER (antlered) × DMU (DMU 12)	–0.1523	0.206	0.55	0.461
ANTLER (antlered) × DMU (DMU 13)	0.0042	0.198	0.01	0.983
ANTLER (antlered) × DMU (DMU 14)	–0.2415	0.208	1.35	0.245
ANTLER (antlered) × DMU (DMU 15)	–0.1737	0.202	0.74	0.389
ANTLER (antlered) × DMU (DMU 16)	–0.1906	0.210	0.82	0.365
ANTLER (antlered) × DMU (DMU 17)	0.0893	0.207	0.19	0.667
ANTLER (antlered) × DMU (DMU 18)	–0.1106	0.213	0.27	0.603
ANTLER (antlered) × DMU (DMU 19)	0.0113	0.200	0.01	0.955
ANTLER (antlered) × DMU (DMU 20)	–0.1498	0.200	0.56	0.454
ANTLER (antlered) × DMU (DMU 21)	–0.1730	0.196	0.78	0.378
ANTLER (antlered) × DMU (DMU 22)	–0.0670	0.201	0.11	0.739
ANTLER (antlered) × DMU (DMU 23)	0.1002	0.207	0.23	0.629
ANTLER (antlered) × DMU (DMU 24)	–0.0355	0.202	0.03	0.861
ANTLER (antlered) × DMU (DMU 25)	–0.0876	0.205	0.18	0.668
ANTLER (antlered) × DMU (DMU 26)	0.2172	0.247	0.77	0.380
ANTLER (antlered) × DMU (DMU 27)	–0.0993	0.207	0.23	0.632
ANTLER (antlered) × DMU (DMU 28)	–0.0207	0.203	0.01	0.919
ANTLER (antlered) × DMU (DMU 29)	–0.2645	0.221	1.43	0.232
ANTLER (antlered) × DMU (DMU 30)	0.0673	0.216	0.10	0.755
YEAR (2000) × DMU (DMU 1)	0.0649	0.162	0.16	0.689
YEAR (2000) × DMU (DMU 2)	–0.0963	0.168	0.33	0.567
YEAR (2000) × DMU (DMU 3)	–0.1121	0.180	0.39	0.535
YEAR (2000) × DMU (DMU 4)	0.0827	0.178	0.22	0.643
YEAR (2000) × DMU (DMU 5)	0.0442	0.173	0.66	0.798
YEAR (2000) × DMU (DMU 6)	0.0122	0.178	0.01	0.945
YEAR (2000) × DMU (DMU 7)	–0.0076	0.168	0.01	0.964
YEAR (2000) × DMU (DMU 8)	0.1011	0.182	0.31	0.578
YEAR (2000) × DMU (DMU 9)	0.1910	0.221	0.75	0.387
YEAR (2000) × DMU (DMU 10)	–0.0713	0.169	0.18	0.673
YEAR (2000) × DMU (DMU 11)	–0.0665	0.164	0.17	0.685
YEAR (2000) × DMU (DMU 12)	–0.2088	0.174	1.45	0.229
YEAR (2000) × DMU (DMU 13)	0.0639	0.166	0.15	0.701
YEAR (2000) × DMU (DMU 14)	0.0161	0.178	0.01	0.928
YEAR (2000) × DMU (DMU 15)	–0.0699	0.171	0.17	0.682
YEAR (2000) × DMU (DMU 16)	0.0344	0.181	0.04	0.849
YEAR (2000) × DMU (DMU 17)	–0.2532	0.177	2.05	0.152
YEAR (2000) × DMU (DMU 18)	–0.1575	0.182	0.75	0.388
YEAR (2000) × DMU (DMU 19)	–0.2177	0.168	1.68	0.200
YEAR (2000) × DMU (DMU 20)	0.0973	0.169	0.33	0.564
YEAR (2000) × DMU (DMU 21)	0.0500	0.164	0.09	0.761
YEAR (2000) × DMU (DMU 22)	0.0350	0.170	0.04	0.837
YEAR (2000) × DMU (DMU 23)	–0.1245	0.176	0.50	0.479
YEAR (2000) × DMU (DMU 24)	–0.0932	0.170	0.30	0.584
YEAR (2000) × DMU (DMU 25)	–0.0390	0.174	0.05	0.823
YEAR (2000) × DMU (DMU 26)	–0.2123	0.221	0.92	0.337
YEAR (2000) × DMU (DMU 27)	0.1123	0.176	0.41	0.524
YEAR (2000) × DMU (DMU 28)	–0.0023	0.172	0.01	0.989
YEAR (2000) × DMU (DMU 29)	0.0723	0.193	0.14	0.708
YEAR (2000) × DMU (DMU 30)	0.1044	0.183	0.32	0.569

rates varied by YEAR, ANTLER, and DMU, and the best model included the interaction terms ANTLER × YEAR, DMU × YEAR, ANTLER × DMU, and YEAR × ANTLER × DMU (Table 5). Average predicted reporting rates ranged from 40 to 46% for antlerless deer, but for antlered deer declined an average of 1% per year from 1990 to 2001 (Fig. 2).

Statewide, harvest estimates for antlered and antlerless deer were precise (CV ≤ 2.4%; Table 6). Harvest estimates by DMU were precise for both antlered (mean CV = 5.7%, range = 2.7–20.9%) and antlerless deer (mean CV = 6.5%, range = 2.6–23.1%). For antlered deer, 95% of CVs by DMU were <10% and for antlerless deer, 90% of CVs were <12%.

Statewide, reported harvests by DMU were correlated with estimated harvest (antlered: $R^2 = 0.942$, $n = 372$; antlerless: $R^2 = 0.900$, $n = 372$), but these relationships did not necessarily hold for individual DMUs. Linear models using reported harvest to predict estimated harvest by DMU were poor for antlered deer (median $R^2 = 0.287$, range = 0.000–0.690; Fig. 3), but generally acceptable for antlerless deer (median $R^2 = 0.909$, range = 0.370–0.982; Fig. 3).

DISCUSSION

Our analyses of reporting rates by hunters indi-

Table 3. Average predicted probability that a hunter reports the harvest of a deer by hunting season and whether the deer is antlered, Pennsylvania, USA, 2000–2001.

		2000		2001	
Season	Antlered	*n*	*P*(report)	*n*	*P*(report)
October	Yes	15	0.457	75	0.522
	No	1,086	0.591	2,079	0.601
Rifle	Yes	20,934	0.356	17,871	0.423
	No	28,737	0.446	22,963	0.466

cate that simply using hunter-reported counts of harvested deer would not serve as a valid index for the harvest of antlered deer (median R^2 = 0.287; Fig. 3). This is because substantial heterogeneity exists in reporting rates among DMUs (Fig. 1), and the reporting rate for antlered deer has declined about 1% per year during 1990–2001 (Figs. 1, 2). In fact, data on reporting rates prior to 1990 indicate that reporting rates for both antlered and antlerless deer have declined since 1982, from nearly 60% for antlered deer and approximately 55% for antlerless deer (PGC, unpublished data). During 1990–2001, reported antlerless harvest was generally correlated with estimated antlerless harvest (median R^2 = 0.909; Fig. 3) because reporting rates did not exhibit a trend over time.

By incorporating heterogeneity in reporting rates, we obtained more accurate estimates of harvest; however, this does not ensure that our estimates were unbiased. Bias in harvest estimates could result by not including important predictive variables in our linear-logistic model that could be related to individual characteristics of hunters. For example, hunters who hunt more often or participate in >1 type of deer hunting are more likely to respond to mail surveys (Martinson and Whitesell 1964, Sen 1972, Shope 1985, Barker 1991, Diefenbach 1993) and might be more likely to report harvest of a deer. However, PGC's current paper-based licensing system does not permit linking license numbers to characteristics of individual hunters in a practical manner. State wildlife agencies with computerized licensing systems might be able to identify characteristics of hunters (e.g., number or types of licenses purchased) that could serve as useful predictive variables of whether a hunter will report the harvest of a deer.

Another factor that could affect the accuracy of harvest estimates is whether hunters who take their deer to meat processors (where PGC personnel field-check deer) are just as likely to report their harvest as hunters who process deer themselves. Independent estimates of statewide antlered and

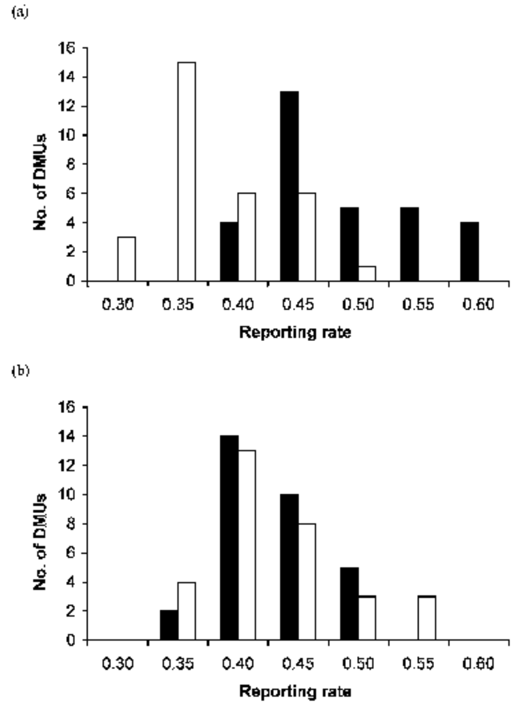

Fig. 1. Distribution of antlered (a) and antlerless (b) reporting rates by deer management unit (DMU), Pennsylvania, USA, 1990 (filled bars) and 2001 (open bars). Reporting rates represent the minimum reporting rate of each group (i.e., 0.30 = 0.30 to <0.35, 0.35 = 0.35 to <0.40).

antlerless harvests from an annual mail survey conducted by the PGC (Diefenbach 1993) were similar (antlered: r = 0.979, P < 0.001; antlerless: r = 0.768, P < 0.006) to our harvest estimates. Consequently, available evidence suggests that our samples were representative and harvest estimates were accurate.

Estimates of statewide harvest were precise, with CVs < 2.5% among years for both antlered and antlerless harvests during the rifle season (Table 6). However, DMUs are the scale at which population size is estimated, and harvest estimates must be estimated at this same scale. We found that harvest estimates for DMUs were precise enough for management purposes (CVs < 12%) in >90% of DMUs.

Failure to account for reporting-rate variability resulted in biased harvest estimates. Traditionally, the PGC had estimated reporting rate by year, DMU, and type of animal, but not by season. Our analysis of 2000–2001 data indicated that this results in biased estimates of harvests during the archery and special antlerless hunting seasons in October and November. In fact, applying rifle-season reporting rates to reported harvest during the archery season resulted in overestimates of har-

Table 4. Harvest estimates ($\hat{H}_{rc}$) and number of harvest report cards received by the Pennsylvania Game Commission for the archery and muzzleloader seasons during Oct–mid-Nov and the regular rifle season in late Nov–early Dec, Pennsylvania, USA, 2000–2001. Reporting-rate season identifies hunting season when deer were field-checked and from which reporting rate was estimated.

Year	Hunting season	Reporting-rate season	Antler type	$\hat{H}_{rc}$	SE($\hat{H}_{rc}$)	CV	95% CI	No. of report cards
2000	Oct	Oct	Antlered	35,842	4,204.7	11.7	28,502 to 45,072	16,200
			Antlerless	38,141	630.2	1.7	36,926 to 39,396	22,405
			Both	73,983	4,254.3	5.8	66,103 to 82,802	38,605
		Rifle	Antlered	45,495	599.9	1.3	44,334 to 46,686	16,200
			Antlerless	49,129	440.8	0.9	48,273 to 50,001	22,405
			Both	94,624	764.6	0.8	93,137 to 96,135	38,605
	Rifle	Rifle	Antlered	193,644	1995.6	1.0	189,772 to 197,595	68,288
			Antlerless	224,874	1608.6	0.7	221,743 to 228,049	100,335
			Both	418,518	2586.2	0.6	413,480 to 423,618	168,623
	Oct + Rifle	Oct + Rifle	Antlered	188,148	3,591.8	1.9	181,239 to 195,321	84,488
			Antlerless	247,776	1,803.3	0.7	244,267 to 251,336	122,740
			Both	435,924	4,033.2	0.9	428,090 to 443,901	207,228
	Oct + Rifle	Rifle	Both	455,070	2,766.2	0.6	449,680 to 460,524	207,228
2001	Oct	Oct	Antlered	31,835	3,236.0	10.2	26,098 to 38,834	16,660
			Antlerless	41,948	652.0	1.6	40,689 to 43,245	25,209
			Both	73,783	3,301.0	4.5	67,592 to 80,542	41,869
		Rifle	Antlered	39,292	487.8	1.2	38,348 to 40,260	16,660
			Antlerless	53,636	504.8	0.9	52,656 to 54,634	25,209
			Both	92,928	719.7	0.8	91,528 to 94,349	41,869
	Rifle	Rifle	Antlered	156,313	1,505.5	1.0	153,390 to 159,292	65,415
			Antlerless	205,829	1,604.7	0.8	202,708 to 208,998	94,778
			Both	362,141	2,224.4	0.6	357,807 to 366,527	160,193
	Oct + Rifle	Oct + Rifle	Antlered	229,486	4,758.9	2.1	220,347 to 239,005	82,075
			Antlerless	263,015	1,830.6	0.7	259,451 to 266,627	119,987
			Both	492,501	5,113.6	1.0	482,580 to 502,626	202,062
	Oct + Rifle	Rifle	Both	513,142	3,159.1	0.6	506,987 to 519,371	202,062

vest by 26–28%, although the resulting bias in total annual harvest was relatively small (<4%) because most deer are harvested during the rifle season.

Reporting rates estimated from statewide mail or telephone surveys and statewide reported harvest probably should not be applied to individual DMUs. For example, we found that reporting rates ranged from 32 to 58% across DMUs. As a result of reporting-rate variability, field-checks of harvested deer (this study) and mail or telephone surveys (Steinert et al. 1994, Rupp et al. 2000, Taylor et al. 2000) used to estimate reporting rates should collect data at the level needed for management.

For hunted populations, harvest data often form the basis of population assessments, and use of reported harvests—even in the most basic methods—can result in faulty conclusions. For example, under nonselective antlered harvest regulations, antlered harvests may be used as an index to population abundance (Strickland et al. 1994). Based on the declining trend of reporting rate and reported antlered harvests (Table 6, Fig. 1), we would con-

Table 5. Linear-logistic models created to estimate the probability of hunters reporting harvest of white-tailed deer during the rifle season in Pennsylvania, USA, 1990–2001, and ranked using Akaike's Information Criteria (AIC). Number of parameters (k) and ΔAIC values are given. The full model (k = 756, n = 497,545) contained the following variables: year of harvest (YEAR), sex of deer (SEX), type of deer (ANTLER), deer management unit where harvested (DMU), and interaction terms (YEAR × ANTLER, YEAR × DMU, YEAR × SEX, ANTLER × DMU, YEAR × ANTLER × DMU).

Model variables	k	ΔAIC
YEAR, ANTLER, DMU, YEAR × ANTLER, YEAR × DMU, ANTLER × DMU, YEAR × ANTLER × DMU	744	0.00
YEAR, SEX, ANTLER, DMU, YEAR × ANTLER, YEAR × DMU, YEAR × SEX, ANTLER × DMU, YEAR × ANTLER × DMU	756	16.45
YEAR, ANTLER, DMU, YEAR × ANTLER, YEAR × DMU, ANTLER × DMU	414	304.29
YEAR, SEX, ANTLER, DMU	44	2,084.88
YEAR, ANTLER, YEAR × ANTLER	24	4,907.39
YEAR, SEX, ANTLER, YEAR × ANTLER, YEAR × SEX	36	4,924.43

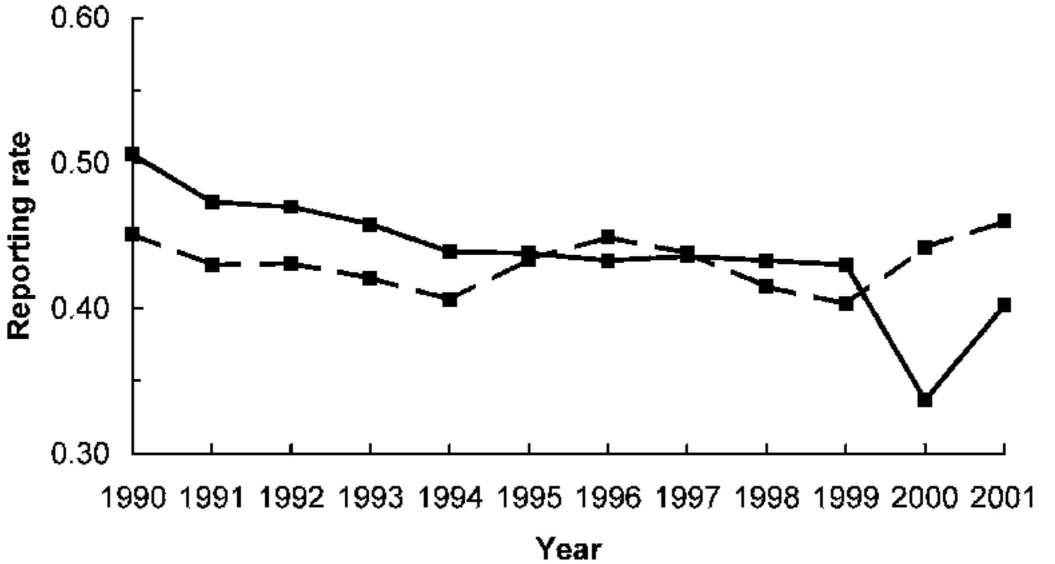

Fig. 2. Average proportion of harvested antlered (solid line, n = 220,467) and antlerless (dashed line, n = 277,078) white-tailed deer reported to the Pennsylvania Game Commission via a report-card registration system, Pennsylvania, USA, 1990–2001.

clude that the deer population had declined between 1990 and 2001 when in fact the deer population increased (PGC, unpublished data).

Population reconstruction, a straightforward estimation technique that uses typical harvest data (Downing 1980), has been recommended as a minimal technique for harvest management (Roseberry and Wolff 1991). Population reconstruction assumes that the fraction of deaths included in the model remains consistent from year to year (Downing 1980). In Pennsylvania, reported harvests were not a consistent fraction of the total harvest and would violate the assumption and lead to erroneous population estimates. Similarly, differences between antlered and antlerless reporting rates highlight the problem of reported harvest ratios as indices to total harvest ratios. In these simple examples, our results clearly demonstrate the risk of using reported harvests as indices of total harvest.

Variable reporting rates are not unique to a report-card registration system. Check or registration stations are the most common method for hunters to report harvested deer, but reporting rates are difficult or impossible to quantify (Strickland et al. 1994, Rupp et al. 2000). Without report-

Table 6. Harvest estimates ($\hat{H}_{rc}$) and number of harvest report cards received by the Pennsylvania Game Commission for antlered and antlerless deer during the regular rifle season in late Nov–early Dec, Pennsylvania, USA, 1990–2001.

	Antlered					Antlerless				
Year	$\hat{H}_{rc}$	SE($\hat{H}_{rc}$)	CV	95% CI	No. of report cards	$\hat{H}_{rc}$	SE($\hat{H}_{rc}$)	CV	95% CI	No. of report cards
1990	176,652	1,749.1	1.0	173,257 to 180,114	83,485	248,310	5,280.4	2.1	238,174 to 258,877	103,611
1991	144,493	1,433.6	1.0	141,710 to 147,330	68,280	228,873	4,759.8	2.1	219,732 to 238,394	95,875
1992	152,323	1,414.7	0.9	149,575 to 155,121	71,073	181,537	3,688.6	2.0	174,450 to 188,912	76,510
1993	149,318	1,355.4	0.9	146,685 to 151,998	68,245	228,977	5,433.9	2.4	218,572 to 239,877	88,100
1994	145,077	1,429.9	1.0	142,301 to 147,907	63,388	237,779	5,281.1	2.2	227,651 to 248,357	88,043
1995	167,737	1,528.0	0.9	164,769 to 170,759	73,036	229,962	4,476.6	1.9	221,354 to 238,905	96,627
1996	136,359	1,349.9	1.0	133,739 to 139,031	58,647	164,819	3,326.5	2.0	158,427 to 171,469	73,544
1997	156,320	1,459.5	0.9	153,485 to 159,207	67,824	199,038	4,117.2	2.1	191,131 to 207,273	86,288
1998	158,542	1,400.1	0.9	155,821 to 161,310	68,116	174,169	3,944.0	2.3	166,609 to 182,072	71,816
1999	166,340	1,516.9	0.9	163,393 to 169,340	70,804	148,234	3,537.4	2.4	141,461 to 155,331	59,595
2000	204,203	2,186.0	1.1	199,963 to 208,533	68,290	227,480	5,045.8	2.2	217,803 to 237,587	100,310
2001	164,740	1,646.1	1.0	161,172 to 167,825	65,427	208,387	4,360.5	2.1	200,014 to 217,110	94,782

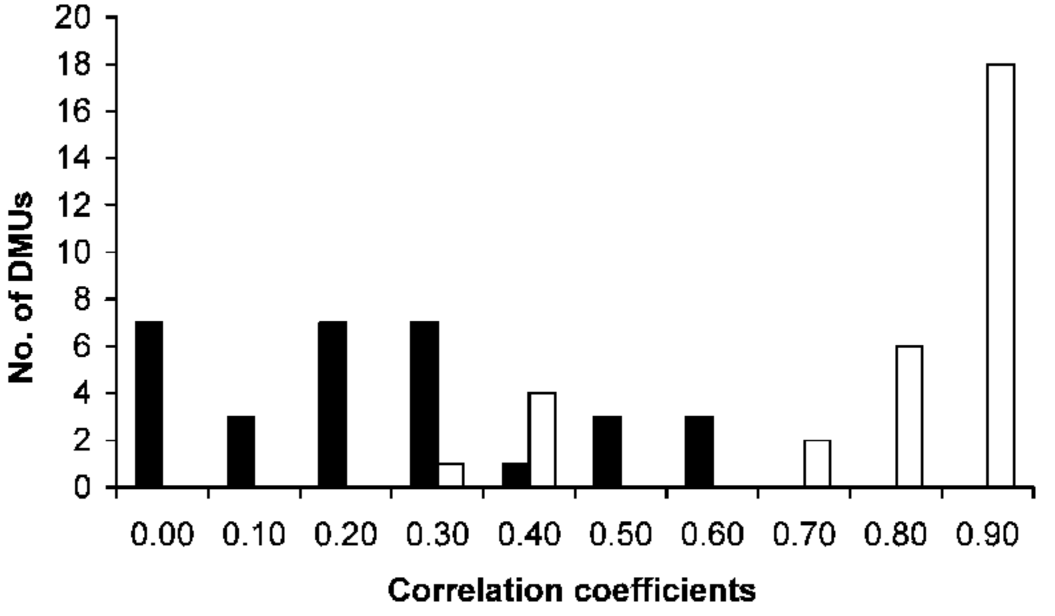

Fig. 3. Correlation coefficients (R^2) of reported and estimated harvests for antlered (filled bars) and antlerless (open bars) white-tailed by deer management unit (DMU), Pennsylvania, 1990–2001. Correlation coefficients represent the minimum coefficient of each group (i.e., 0.00 = 0.00 to <0.10, 0.10 = 0.10 to <0.20).

ing-rate estimates, managers must make assumptions concerning homogeneity of reporting rates to make inferences about harvest. However, for both incentive-based and mandatory check or registration stations, reporting rates may vary considerably (Goldstein 1998, Gove et al. 2002). Land ownership and type of animal may also influence compliance with check stations (Rupp et al. 2000). Although each registration system contains distinct properties that affect hunter compliance, reporting-rate variability does not seem to be unique to a particular registration system.

MANAGEMENT IMPLICATIONS

Reliable data should be the basis for management and research (White 2001), and counts may not constitute reliable data when used as an index (Anderson 2001, MacKenzie and Kendall 2002, Williams et al. 2002). For hunted populations, harvest data often form the basis for population assessments; however, reported harvests may not be a reliable index of total harvest. In Pennsylvania, reporting rates varied temporally, spatially, by type of deer, and by hunting season despite a harvest registration system that has changed little over 2 decades. We recommend regular estimation of reporting rates at the DMU scale to ensure reliable harvest estimates, and we caution against assuming a constant reporting rate, even in consistent harvest registration systems.

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