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Estimating Time of Death of Deer in Missouri; A Comparison of Three Indicators*

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ABSTRACT: Estimation of time of death (TOD) of white-tailed deer is important to wildlife law enforcement officers. The purpose of this study was to develop and test a model for estimating TOD of white-tailed deer in Missouri. We compare the utility of carcass temperature, pupil diameter, and rigor mortis as TOD indicators. The effects of body size, ambient temperature, and various carcass handling methods on the estimate were also examined. Data were collected from 1484 deer during the 1995–96 and 1996–97 hunting seasons. Stepwise regression indicated that all three indicators were significant and that body size and ambient temperature could influence the model. Predictive equations were developed for various combinations of the indicators based on practicality and statistical probabilities. TOD was estimated for 28 animals where the exact TOD was known. There was no significant difference between the estimated and known TOD ($p = 0.759$) and the average of the absolute differences is 1 h and 28 min.

KEYWORDS: forensic science, forensic pathology, time of death, postmortem interval, carcass cooling, rigor mortis, deer, Missouri, wildlife law enforcement

Time of death (TOD) estimation for wildlife species has been designated as the most desired wildlife law enforcement tool (1). This ability would allow officers to confirm or deny whether an animal had been taken during legal seasons and shooting hours or decide if further investigation is necessary. Research into this area has been done on several species including some in waterfowl and upland game bird families and some in the family Cervidae. Of the cervids, white-tailed deer (*Odocoileus virginianus*) is the species that has received the most attention. However, this attention has been sporadic and brief in duration and without unity among state or federal agencies.

Most of the work in this field has been initiated by wildlife law enforcement officers working alone who see the possibility of estimation of TOD as an ability which would greatly enhance their effectiveness. There are some cases of various university faculty and students pursuing research in this area but little of the information from these studies has been published and is therefore not readily available (2). Some of the states that have joined wildlife law enforcement agencies and universities and published their findings are Maine (3), Illinois (4), Iowa (5), Utah (6), and Oregon (7). Some of these publications are re-examinations of data from Gill and O'Meara's 1965 study (3), which is generally considered to be the first white-tailed deer TOD estimation project. TOD indicators examined in these studies include carcass temperature, eye appearance and pupil size, potassium level of the vitreous humor, degree of rigor mortis present, and presence and abundance of various members of the entomological fauna. Two of these indicators, chemical levels of the vitreous humor and entomological community present, require the collection of specimens from the field and subsequent analyses under laboratory conditions.

The purpose of this study was to develop and test a model for estimating time of death of white-tailed deer in Missouri. Beattie and Giles (1) cite the need for forensic techniques for wildlife law enforcement officers to be both field applicable and of instantaneous nature. For these reasons we chose to compare the utility of carcass temperature, pupil diameter, and rigor mortis as TOD indicators.

Methods

The following data were collected during the fall and winter seasons of 1995–96 and 1996–97 at firearms deer season check stations, special area management hunts, and crop depredation harvests: date, location, carcass temperature, pupil diameter, rigor mortis, weight, chest girth, forearm girth, age, sex, ambient temperature, estimated or actual TOD, time of day measurements of animal were made, and postmortem interval (PMI).

Temperatures in previous studies (3,4,8) and numerous wildlife forensic manuals (9–12) have been measured in degrees Fahrenheit (F). Woolf et al. (4) state that this is done because potential users are more familiar with this scale and comparisons among other data sets are easier. We agree with this statement and therefore chose to use F in our analyses involving temperatures.

Carcass temperature was determined by measuring the temperature of the center of the muscle mass of the thigh as described by Gill and O'Meara (3). The temperature was taken on the inside of whichever thigh was laying on the substrate at the time of data collection. The highest temperature (measured by adjusting the thermometer insertion depth) was recorded for each animal. The thermometers used were digital (Taylor® Model #9840) with resolution of 0.10°F and readings displayed at 1 second intervals.

The medial pupil diameter was measured to the nearest 1⁄10 mm with dial calipers. In cases where it was necessary to illuminate the eye to discern the pupil a standard flashlight was used (9). To facilitate testing for any difference in size between the two pupils of an animal, both pupil diameters were recorded for a number ($n = 40$) of animals. Pupil measurements were not recorded in cases of obvious head trauma.

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Rigor mortis was measured by the use of a device (13) designed to duplicate the flexion of the wrist joint. This joint was selected because it is typically the last joint to undergo the onset of rigor (3,14) and is the most practical location for measurement. The device (Torque-Tubes) was constructed of two pieces of pipe designed to fold together to 90°. The lower piece of pipe had two 9/16″ nuts (one on either side) welded on at the bottom. This nut accepted a torque wrench (K-D Tools® Model #2651) which measured the torque (in inch-pounds) necessary to flex the joint to an angle of 90°. Rigor was determined by sliding the Torque-Tubes on the foreleg so that the upper half of the device encompassed the radius and ulna and the lower half encompassed the metacarpals. To determine if there were differences in rigor of the foreleg from either side of the animal, both rigor measurements for a number of animals ($n = 45$) were recorded during part of the study period. Rigor of the foreleg was not measured on animals with gunshot wounds (GSW) located in either the limb or lower shoulder area or when the stiffening had been previously broken (by hunter handling). To ensure against this possibility, research personnel handled all carcasses in the course of data collection. Rigor was only measured on animals when it was determined that the forelegs were and had been straight out (as if the animal were standing) during the PMI.

Weight was determined (± 0.45 kg) using platform scales (Toledo® Model #4182) that had been certified for legal trade. Weight was recorded as either field-dressed (completely eviscerated) or whole (live weight, minus blood loss)(15). Chest girth was measured directly behind the shoulder with a vinyl tape while the animal was lying on its side with the legs straight (16). Forearm girth was measured at a distance from the joint of the radius/ulna and metacarpals (wrist) equal to half the length of the ulna and was also made with the limb extended. Both measurements were rounded up to the nearest 0.32 cm (17) and recorded for both field-dressed and whole animals. Age was determined by tooth wear and replacement (18). Age was classed as fawn when <1-year-old, yearling when >1-years-old but less than 2-years-old, and adult when ≥2-years-old.

Ambient temperature (a/t) was recorded hourly using a standard outdoor mercury thermometer positioned approximately six feet off the ground in a shaded area (3) where data were being collected. The a/t recorded for each animal was the average of the hourly temperatures between the TOD and the time the animal was measured.

Time of death for most of the animals was determined by asking the hunter for the TOD within ±15 min. This time was recorded as estimated TOD and data from these animals were used to develop multiple regression equations for estimating TOD. For animals killed during crop depredation hunts TOD was recorded as actual or known and data from these animals were used to test the estimation models. The PMI was determined by subtracting the TOD from the time the animal was measured. PMI was recorded in hours and quarter-hours, with quarter-hours being rounded to the next quarter-hour when one was exceeded by 8 min.

Statistical analyses were done using the Minitab® 11 statistical package on Gateway2000® P5-120 computers. Stepwise regression of all the variables and indicators was used to determine which would account for most of the variation in the data. To investigate the relationship between the variables and the PMI estimate, the data were also divided into three groups. These groups were based on the way the carcass was handled and the ambient temperature when the animal was killed. Allometric influences on the PMI estimate were investigated by assigning the data to morphometric size classes. These were based on frequencies in the distribution of the annual harvest. In Missouri, many of the animals harvested will field-dress less than 46.5 kg, a smaller portion will be between 46.5 and 77.25 kg, and very few will weigh more than 77.25 kg. Comparison of multiple regression equations was done as described by Zar (19). The experimentwise error rate was controlled in multiple comparisons using the Dunn-Sidak method (20). The Wilcoxon matched pairs test was used for all paired comparisons.

Results

Animals for this study came from 26 counties in the state (Fig. 1). A total of 1484 deer was measured. Of this total, 1168 were either yearlings or adults and the remaining 316 were fawns. Field-dressed weights ($n = 1411$) ranged from 10.45 to 96.82 kg (Fig. 2). Ambient temperatures (a/t) ranged from −6 to 78°F.

No significant difference was found between left and right measurements of both pupil diameter and rigor (Wilcoxon statistic 438.5 and 580.5, $p = 0.707$ and 0.481, respectively. Stepwise regression on the entire data set showed that ambient temperature was the only significant variable ($p = 0.001$), whereas all three indicators (thigh temperature, rigor, and pupil diameter) were significant ($p < 0.0001$).

The data were then divided into three groups based on either ambient temperature or certain carcass handling methods or conditions. The slopes of the regression lines from the various groups were tested to determine the effects of partitioning on the variance. The first group consisted of animals ($n = 912$) from the complete range of ambient temperatures that had been field-dressed but without remarkable handling conditions. Ambient temperature was significant to the model for this group ($p = 0.002$). The second group consisted of animals ($n = 78$) which had been killed when the ambient temperature was below 20°F that had been field-dressed but without remarkable handling conditions. Ambient temperature was not significant to the model for this group ($p = 0.495$). These two groups were significantly different ($F = 4.88$, df = 902, $p = 0.0004$) meaning that for field-dressed animals, different temperature-based models would be needed, one if the PMI ambient temperature was 20°F or higher and one if it was below 20°F. The third group consisted of animals ($n = 156$) that had been subject to any one or any combination of conditions which may effect the cooling rate. These conditions are: 1) washed out after field-dressing ($n = 67$), 2) hauled in the trunk of a car or in the bed of a pickup with a camper shell ($n = 48$), 3) not field-dressed ($n = 32$), 4) stored or hauled with a group of carcasses (at least 4 in entire group) ($n = 9$). This group was significantly different from both the 20°F or higher group ($F = 34.94$, df = 980, $p < 0.0001$) and the below 20°F group ($F = 76.36$, df = 226, $p < 0.0001$).

These three groups were further subdivided by carcass size based on the measurements of weight and total girth (t-girth, the sum of chest and forearm girth). Because both measurements resulted in the same coefficient of determination (R^2) and t-girth is easier to measure (13), we chose to use it in our final analyses. The subdivisions based on size were: 1) t-girth of 87 cm or less, 2) t-girth >87 but <110 cm, 3) t-girth 110 to 120 cm, and 4) t-girth 120 cm or greater.

Carcass size increased the explained variance of the 20°F or higher group ($F = 4.98$, df = 892, $p < 0.0001$). For this group, the two smaller sizes ($n = 58$ and 375, respectively) were not different ($F = 2.52$, df = 457, $p = 0.0578$) and the two larger sizes ($n = 268$ and 134, respectively) were not different ($F = 1.89$, df = 435, $p = 0.191$), but the two middle sizes were different ($F = 4.10$, df = 693, $p = 0.0022$). Therefore, for field-dressed animals killed when the ambient temperature for the PMI is 20°F or higher, one model is

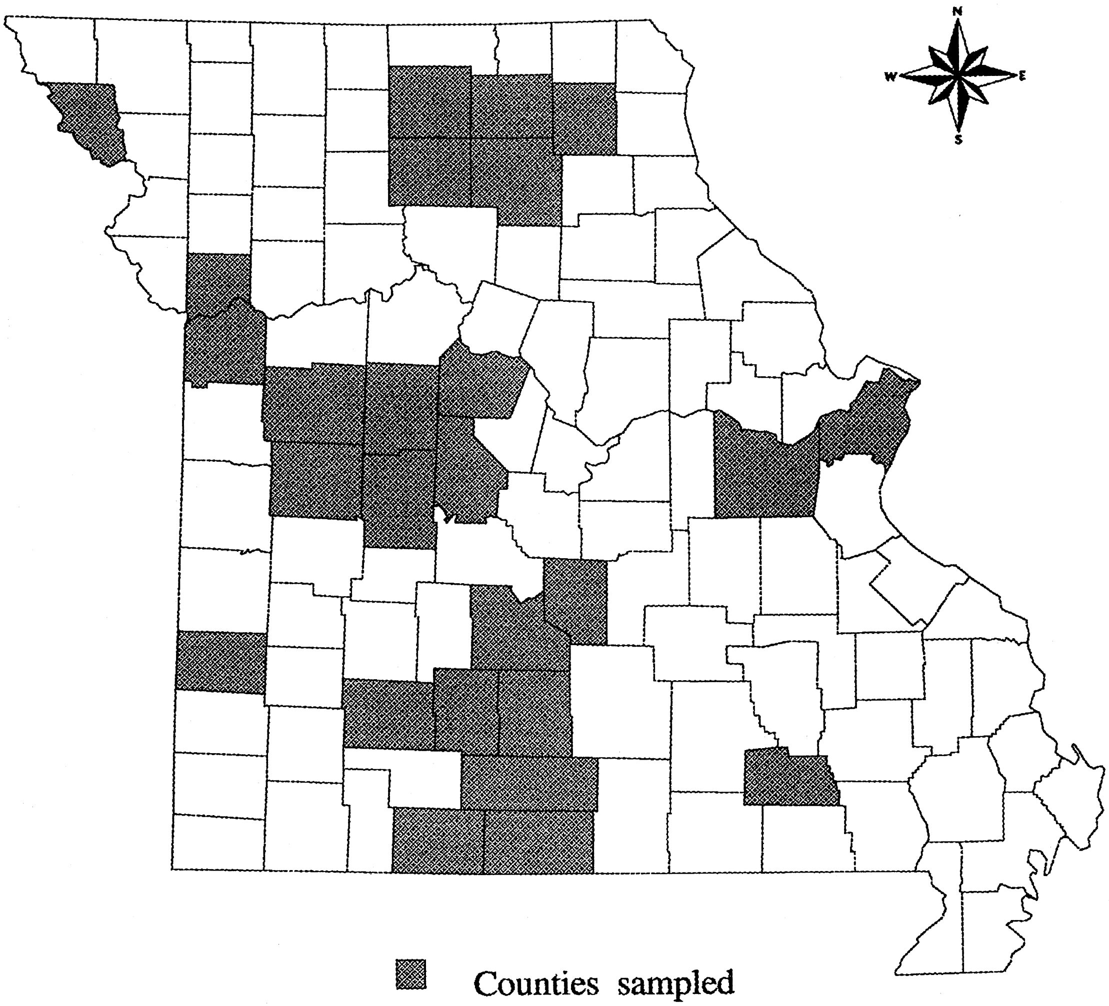

FIG. 1—*Distribution of counties sampled.*

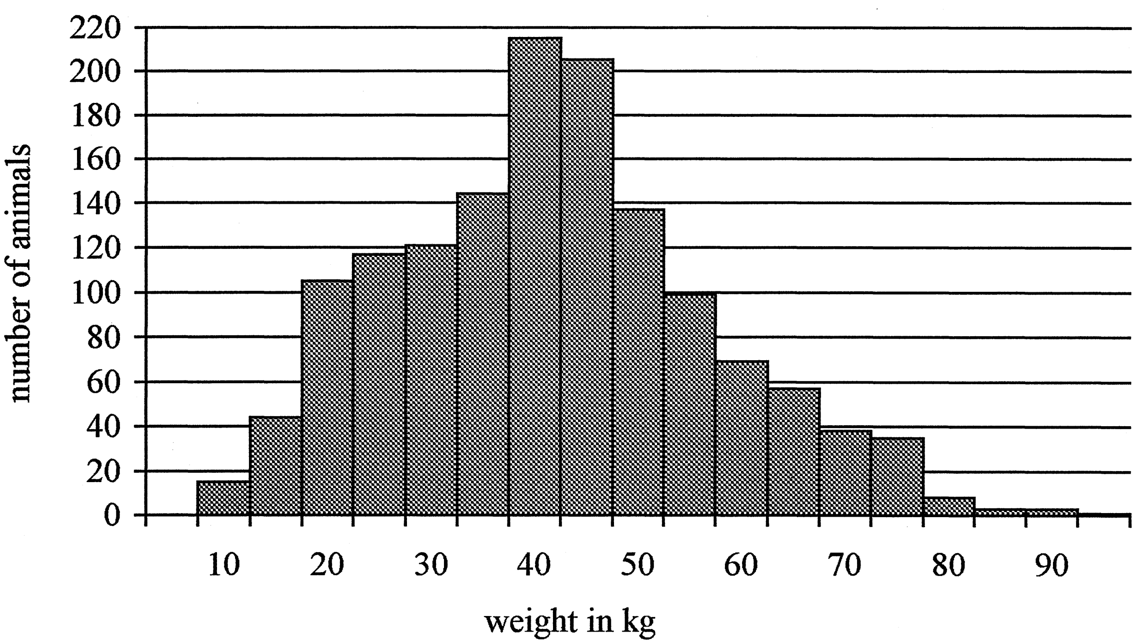

FIG. 2—*Distribution of field-dressed weights.*

needed for small animals and a different one is needed for larger animals. Carcass size did not explain more of the variance associated with the below 20°F group ($F = 1.14$, $df = 59$, $p = 0.6591$) or the group with remarkable handling conditions ($F = 1.25$, $df = 142$, $p = 0.490$).

More of the variance could be explained for the latter group when considering the effects of the different handling conditions ($F = 22.2$, $df = 119$, $p < 0.0001$). The group of animals that had been washed out was not different from the group that had been hauled in a trunk or under a camper shell ($F = 1.86$, $df = 97$, $p = 0.242$) and the group of not dressed animals was not different from the group of animals that had been kept in physical contact with other carcasses ($F = 2.04$, $df = 22$, $p = 0.224$).

These groupings were then reclassified by significant differences. PMI estimation models and their corresponding statistics for these 5 groups are shown in Table 1. Models were also derived for Groups 1, 2, and 3 for different combinations of indicators (Tables 2, 3, and 4).

PMI estimates were then made using the measurements from 28 animals where the actual TOD was known. The a/t for these animals ranged from 44.8 to 65.1°F and field-dressed weights ranged from 18 to 47 kg. Total girth ranged from 74 to 114 cm and therefore these animals fit the criteria of either Group 2 or 3. There was no significant difference (Wilcoxon statistic 217.0, $p = 0.759$) between the estimated and actual TOD (Fig. 3) and the average of the absolute differences is 1 h and 28 min.

TABLE 1—*PMI (γ) estimation models for various groups using the indicators thigh temperature (t/t), pupil diameter (p/d), and rigor (rig), and the variable ambient temperature (a/t).*

Group*	Model	R^2	SD	*n*
1	γ = 13.4 − (0.095l t/t) − (0.198 p/d) + (0.0126 rig)	0.631	0.9792	79
2	γ = 17.1 + (0.0139 a/t) − (0.145 t/t) − (0.654 p/d) + (0.0462 rig)	0.792	1.241	467
3	γ = 23.7 + (0.0159 a/t) − (0.194 t/t) − (0.121 p/d) + (0.0144 rig)	0.746	1.678	445
4	γ = 17.2 + (0.0155 a/t) − (0.119 t/t) − (0.174 p/d) + (0.0109 rig)	0.585	1.681	107
5	γ = 42.1 − (0.0231 a/t) − (0.364 t/t) − (0.278 p/d) + (0.638 rig)	0.958	1.759	32

* Group legend:
1 = Animal killed when a/t was less than 20°F.
2 = Animals with a t-girth <110 cm killed and field-dressed when a/t was ≥20°F.
3 = Animals with a t-girth ≥110 cm killed and field-dressed when a/t was ≥20°F.
4 = Animals either washed out or hauled in a closed vehicle.
5 = Animals either not field-dressed or hauled with a group.

TABLE 2—*PMI (γ) models for animals killed when the ambient temperature (a/t) was below 20°F using various combinations of the indicators thigh temperature (t/t), pupil diameter (p/d), and rigor (rig).*

Model	R^2	SD	CI*
γ = 13.4 − (0.95l t/t) − (0.198 p/d) + (0.0126 rig)	0.613	0.9792	±1.96
γ = 15.0 − (0.113 t/t) − (0.173 p/d)	0.569	1.033	±2.07
γ = 13.2 − (0.121 t/t) + (0.0108 rig)	0.562	1.042	±2.08
γ = 14.6 − (0.134 t/t)	0.531	1.077	±2.15

* 95% confidence interval in hours.

TABLE 3—*PMI (γ) models for animals killed with a t-girth <110 cm killed and field-dressed when ambient temperature (a/t) was ≥ 20°F using various combinations of the indicators thigh temperature (t/t), pupil diameter (p/d), and rigor (rig).*

Model	R^2	SD	CI*
γ = 17.1 + (0.0139 a/t) − (0.145 t/t) − (0.0654 p/d) + (0.0462 rig)	0.792	1.241	±2.49
γ = 23.0 + (0.0183 a/t) − (0.195 t/t) − (0.0697 p/d)	0.714	1.462	±2.92
γ = 18.0 + (0.0128 a/t) − (0.0157 t/t) + (0.0478 rig)	0.791	1.250	±2.50
γ = 23.0 + (0.0215 a/t) − (0.204 t/t)	0.712	1.468	±2.94
γ = 11.0 − (0.0357 a/t) − (0.0531 p/d)	0.290	2.304	±4.61
γ = 2.22 − (0.0232 a/t) + (0.0984 rig)	0.513	1.908	±3.82

* 95% confidence interval in hours.

TABLE 4—*PMI (γ) models for animals killed with a t-girth ≥110 cm killed and field-dressed when ambient temperature (a/t) was ≥20°F using various combinations of the indicators thigh temperature (t/t), pupil diameter (p/d), and rigor (rig).*

Model	R^2	SD	CI*
γ = 23.7 + (0.0159 a/t) − (0.194 t/t) − (0.121 p/d) + (0.144 rig)	0.746	1.678	±3.36
γ = 26.4 + (0.0211 a/t) − (0.220 t/t) − (0.0116 p/d)	0.724	1.748	±3.50
γ = 23.6 + (0.0187 a/t) − (0.212 t/t) + (0.0155 rig)	0.740	1.696	±3.40
γ = 26.5 + 0.0244 a/t) − (0.238 t/t)	0.719	1.764	±3.53
γ = 13.7 − (0.0231 a/t) − (0.7160 p/d)	0.379	2.621	±5.24
γ = 2.61 − (0.0278 a/t) + (0.0509 rig)	0.333	2.716	±5.43

* 95% confidence interval in hours.

Discussion

Gill and O'Meara (3) used thigh temperature from whichever thigh was down at the time of data collection. Subsequent researchers have typically used this method for determining carcass temperature (4,5,7,9). There is little reason to believe one thigh would cool more quickly than the other because in most cases there is no reason for the mass to surface area ratio to differ between the two. Further, since there is a .50 probability for either thigh to be down, measurements from past studies should represent both sides equally. Because of these facts, a comparison of the two thigh temperatures of the same animal was not examined in this study. However, we found no significant difference between left and right measurements for both pupil diameter and rigor. Since the process which causes the changes in these measurements is a function of the cooling rate, these findings can be extrapolated to surmise that there is no difference in the cooling rate between the left and right sides of a carcass. This does not mean the cooling rate for an animal placed in water is the same as the cooling rate for one left in the back of a vehicle parked directly in the sun. It means that whatever environmental condition the animal is left in, both sides of the carcass will cool at the same rate. Therefore, an officer may obtain the carcass temperature from either thigh of the animal with confi-

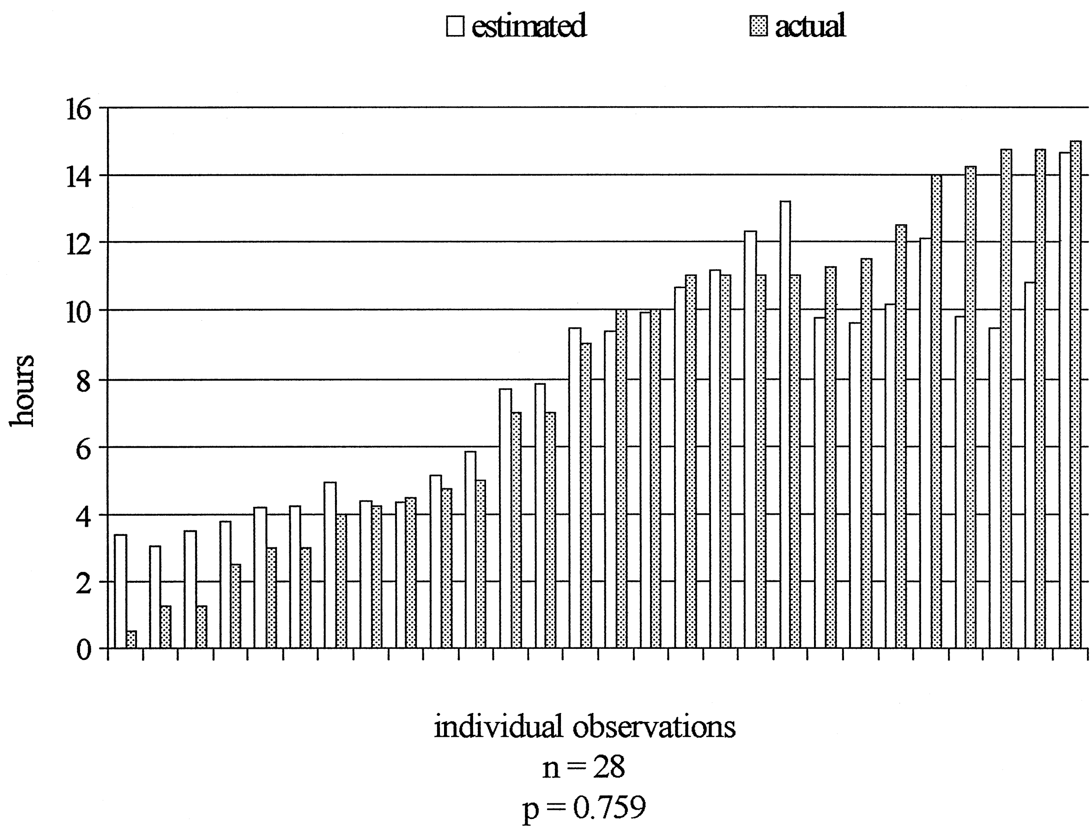

FIG. 3—*Comparison of estimated and actual PMI for field-dressed animals.*

dence that the temperature of the other thigh will be, statistically, the same.

Our findings indicate that in most cases the size of an animal can play an important part in determining TOD. Size can be determined by weight or morphological measurements without any change in the explained variance. Because girth measurements can conveniently be made by use of a tape measure, they were the measurement of size used for final analyses in this study. This eliminates the need to estimate the weight of an animal and then estimate the TOD based on the estimated weight. The decisive t-girth measurement is about 110 cm. This measurement corresponds to animals with a field-dressed weight of about 46.25 kg, and results in one model for animals which would generally fall in the yearling or fawn class and one model for adults. These two models are for animals which have been typically field-dressed and hauled in a pickup to a check station. This is the most common scenario the wildlife law enforcement agent will encounter. However, the average ambient temperature during the PMI effects the utility of size measurements and can drastically effect estimating TOD. At ambient temperatures less than 20°F neither the a/t or girth measurements are significant to the TOD model and the rate of cooling differs from that of animals that have been killed when the temperature was at least 20°F.

The method with which a carcass has been handled can also effect estimating the TOD. For the handling methods investigated in this study, the size of the animal was statistically unimportant. That is to say that the way the carcass was handled had a greater effect on the estimate than the size of the animal. The fact that the TOD for carcasses that had either been washed out or hauled in a closed vehicle could be estimated with the same model seems improbable. A possible explanation of this is that perhaps the animals washed out were washed long enough to change any initial cooling plateau (as evidenced by the fact that the slope of that regression equation differed from animals which hadn't been washed out) but not long enough to make a drastic change in the rate of cooling. Likewise, the length of time a carcass spent in the trunk of a vehicle may have effected the initial cooling plateau and not necessarily the actual rate of cooling. Because the length of time water was running into a carcass and the distance traveled with the carcass in the trunk were not recorded, further analysis is not possible. The finding that whether a carcass had not been field-dressed or had been hauled in immediate contact with other carcasses had the same effect is logical. Both conditions result in reducing the mass to surface area ratio, which reduces the cooling rate (21).

Estimation models were derived for Groups 1, 2, and 3 for various combinations of TOD indicators. Because pupil diameter and rigor are a function of cooling, the utility of either of these indicators considered without thigh temperature is minimal and would be difficult to defend in a court of law. For Group 1 the effect of extreme cold can completely eliminate the use of both pupil diameter and rigor, because the body parts that these measurements come from can be frozen quite quickly (within about four hours at ambient temperatures below 20°F, by our observations). If an officer should become involved in an investigation during these conditions and feel compelled to make an estimate he should exercise great discretion in choosing to use the models that include these two indicators. We recommend they be used only if the officer can, on examination of the eye, determine freezing has not yet occurred. However, when either of them can be used in conjunction with thigh temperature there is a marked increase in the coefficient of determination. This would serve to increase corroboration and could be influential to the court. The highest degree of corroboration would of course be achieved when all three indicators are used. On the other hand, the number of deer hunting days when the a/t stays below 20°F are few in Missouri. Consequently, the number of times in an officer's career he might need to estimate TOD for these animals should be few.

For the remaining groups (4 and 5) there are some confounding facts to consider. For these groups the immediate effect of manipulation of the initial plateau is evident. To be conservative, that is to give the hunter the benefit of the doubt, TOD estimation for these two groups should not be made unless all three indicators are available. A larger sample of animals from these groups might make TOD estimation more feasible, but the conditions under which these data were collected are not frequent enough to make increasing the sample size an efficient undertaking.

The coefficients of determination in this study compare favorably with previously published reports. However, previous publications have typically used a much smaller sample size and repeated observations on the same animals. This makes the introduction of bias due to dependency of observations a possibility. Also, variation due to geographical location is not considered if the sample is small or has been taken from one location. These conditions and the fact that these studies were not done in Missouri would most likely come under attack in a Missouri court.

The present study has several aspects that make it of more utility to Missouri wildlife law enforcement officers. The fact that the sample is so large and comes from all geographic regions of the state increases its forensic value. Also, the models herein cover a wider range of ambient temperatures and animal sizes than previously published studies. The objective measurement of rigor mortis has not been previously accomplished. Estimation models were tested and found to be accurate indicators of TOD at the 95% confidence level.

Conclusions

Estimation of time of death of white-tailed deer is an important capability for wildlife law enforcement officers. The most accurate indicator of TOD is carcass temperature, but rigor mortis in the wrist and pupil can increase the amount of variance that is explained by the estimation model.

The methods used in this study can be accomplished on an animal in under five minutes. The development of Torque-Tubes for measuring rigor in the wrist adds an objective measurement of an indication of TOD that may help courts make equitable decisions.

Predictive equations have been developed for various combinations of the indicators based on practicality and statistical probabilities. Whereas more variance may have been explained by analyzing smaller groupings of animals, the successful estimation of the actual TOD of 28 animals based on single observations lends credence to the analyses as they have been done.

This study has shown that in some cases (depending on how the carcass was handled) the size of an animal is important in determining TOD. Using t-girth measurements in the model eliminates the physical work of handling a carcass in preparation of using a scale.

Application of the methods used in this study should be made in conjunction with other time-proven law enforcement techniques. The intent herein is not to "make" cases, but to give the wildlife law enforcement officer a valid tool to corroborate his or her findings about specific cases. The methods and some of the models produced from this study have been tested and shown to be valid for animals fitting certain criteria. The tested models are applicable only to animals that are within the bounds of these criteria. Specifically, this means animals having a t-girth from 60.0 cm to and including 142.0 cm which were killed when the ambient temperature was from 20 to 78°F and that have not been dead over 15 h (or only until the carcass temperature equals the ambient temperature). We have also used these methods and the model for animals that have not been field-dressed (on one occasion) to estimate the TOD of a radio-collared animal that was located because the mortality switch in its transmitter was activated. This animal died of natural causes and our estimate (PMI = 11 h 18 min) was within 2 h of the last 'live' signal from the transmitter. Because the transmitter was set to enter mortality mode after a period of motionless lasting 4 h, we feel our estimate was very much within reason. In this case the animal was located before any scavenging had occurred. In instances where gross disarticulation has already been achieved these methods would be of little utility.

Although the remaining models have not been statistically tested, the validation of the models that were tested give some degree of credence to those that were not. However, further testing may be necessary to satisfy the court. These conclusions cause us to consider how wildlife law enforcement officers might apply the methods described in this paper. We recommend the following approach.

Because the ambient temperature is required for most of the PMI models, officers should record the ambient temperature hourly during the daylight hours of the appropriate seasons. This information may come from regional weather stations or local radio stations because there is normally little difference in temperature across an officer's jurisdiction. When encountering a 'suspect' animal the officer should make a few prima facie judgments by asking some innocuous questions. A good starting list might include: 1) What was the animal doing when you shot it? (running, bedded, etc.), 2) Did you field-dress it immediately? (within 15 or 30 min, an hour, etc.), 3) Do you have any reason to believe this animal was unhealthy? (previously wounded, parasites apparent, etc.), 4) Did you wash the animal after you dressed it? (brief rinsing doesn't matter, prolonged washing or immersion does), 5) How long has the animal been here? (location is important; in an open pickup, trunk of a car, inside of a van, in contact with other animals, etc.), 6) What time did you kill this animal and were any of your hunting companions with you when you shot it? This list is not meant to be exhaustive and the experienced officer will be able to determine if other questions may yield more information. The two girth measurements necessary to determine total girth should be made at the end of this initial interview. The officer should then determine which of the TOD indicators may be usable from the carcass in question. For example, if the animal was dispatched by a mortal head wound the officer should not use pupil diameter, or, if the limbs have been folded in toward the animal's trunk one would not use the rigor measurement. According to the information obtained in this manner, the officer should proceed by using the following dichotomous key to determine which TOD estimation model (from Tables 1, 2, 3, and 4) to use.

1a. Ambient temperature below 20°F. Go to 2
1b. Ambient temperature $\geq$ 20°F. Go to 5
2a. All indicators usable. Table 2, 1st model
2b. Some indicators not usable. Go to 3
3a. Thigh temperature usable; rigor and pupil diameter not usable. Table 2, 4th model
3b. Thigh temperature and one other indicator usable. Go to 4

4a. Thigh temperature and pupil diameter usable. Table 2, 2nd model
4b. Thigh temperature and rigor usable. Table 2, 3rd model
5a. Ambient temperature ≥20°F; atypical handling conditions. Go to 6
5b. Ambient temperature ≥20°F; typical handling conditions. Go to 7
6a. Carcass either washed out or hauled in a closed vehicle. Table 1, 4th model
6b. Carcass either not field-dressed or hauled/stored in a group. Table 1, 5th model
7a. T-girth <110 cm. Go to 8
7b. T-girth ≥110 cm. Go to 11
8a. All indicators usable. Table 3, 1st model
8b. Some indicators not usable. Go to 9
9a. Thigh temperature only indicator usable. Table 3, 4th model
9b. Thigh temperature and one other indicator usable. Go to 10
10a. Thigh temperature and pupil diameter usable. Table 3, 2nd model
10b. Thigh temperature and rigor usable. Table 3, 3rd model
11a. All indicators usable. Table 4, 1st model
11b. Some indicators not usable. Go to 12
12a. Thigh temperature only indicator usable. Table 4, 4th model
12b. Thigh temperature and one other indicator usable. Go to 13
13a. Thigh temperature and pupil diameter usable. Table 4, 2nd model
13b. Thigh temperature and rigor usable. Table 4, 3rd model

The usable indicators should now be measured and their values inserted in the appropriate model. Computation will yield a value in hours (e.g., 4.894). The portion of this value after the decimal point should be rounded to the nearest tenth of an hour (e.g., 0.9) and converted to minutes (e.g., 0.9 h × 60 m = 54 m). In this example the PMI would be 4 h and 54 min. This estimate should *not* be made available to the hunter or used as the determinant time for deciding if the animal was killed during closed hours or, perhaps, out season. At this point the officer is really only concerned with one of two possibilities. One is that the animal was killed before legal hours, the other is that it was killed after legal hours. In the first case the 95% confidence interval (CI)(for whichever model was used to make the estimate) should be subtracted from the estimate. For this example the CI is 2.15 hours (Table 2, 4th model) and therefore the animal may have been killed anytime between 2 h and 45 min and 4 h and 54 min before the measurements were made. If the shortest of these two times is reasonably close (within 30 min) to the starting time of legal hours the hunter may be being truthful and should be given the benefit of the doubt. If the officer is concerned about the possibility the animal was killed after legal hours had closed the appropriate CI should be added to the estimate. By following this approach the officer is being conservative in applying the methods and models of this study; if this is explained to the prosecutor and judge when cases are being considered a decision in favor of justice and the officer's efforts is more likely.

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