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Source: Wildlife Biology, ()

Published By: Nordic Board for Wildlife Research

<https://doi.org/10.2981/wlb.00250>

URL: <http://www.bioone.org/doi/full/10.2981/wlb.00250>

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Considerations on neonatal ungulate capture method: potential for bias in survival estimation and cause-specific mortality

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A recent study of Sitka black-tailed deer *Odocoileus hemionus sitkensis* demonstrated that opportunistic fawn capture yielded left-truncated data and ultimately resulted in overestimating fawn survival and spurious ecological model inference compared to neonates captured via vaginal implant transmitters (VITs). Given the ecological and economic value of ungulates worldwide and the importance of neonate survival to understanding population dynamics, the potential biases in survival estimates and causes of mortality caused by left-truncation must be transparent. Herein, we used a VIT-based dataset from white-tailed deer *Odocoileus virginianus* to examine potential problems with left-truncated data. We manipulated our original VIT-based dataset by randomly assigning age-at-capture to create three hypothetical opportunistic samples. We used the Kaplan–Meier estimator to quantify fawn survival to 16 weeks of age for the original and hypothetical datasets. Additionally, we compared the relative importance of mortality causes between the datasets. Survival for the original, VIT-based dataset was 0.121 (SE = 0.043), while hypothetical datasets yielded overestimates (ranging from 0.191 to 0.234). The hypothetical opportunistic samples overestimated coyote predation as a source of mortality, while underestimating starvation. Because management actions rely on accurate estimates of survival and causes of mortality, we recommend that neonatal survival studies consider biases caused by capture method. For robust estimates of survival, VIT-based samples appear to provide better estimates of survival, as opportunistic samples are biased high. We encourage future work to elucidate the potential for neonate capture technique to affect cause-specific mortality.

Neonatal survival is an important metric for understanding population dynamics of ungulates (Gaillard et al. 1998). However, quantifying neonatal survival remains difficult for many vertebrate species because detection and capture of neonates is challenging (Pike et al. 2008), and the neonatal period tends to be the life history stage of greatest risk (Gaillard et al. 1998, MacNulty et al. 2009). Additionally, neonatal survival and causes of mortality vary as a function of age (Kilgo et al. 2012), which suggests that accurate date-of-birth estimation is important for understanding age-dependent survival and risk exposure (Grovenburg et al. 2014). Further, understanding mortality causes for neonates is important for management because it can affect conclusions about relative contributions of top–down and bottom–up mechanisms (e.g. predation and nutritional constraints).

For years, researchers have used various observational approaches to capture and mark young ungulates for survival

estimation and modeling of covariates that potentially influence survival. For example, Grovenburg et al. (2012) used nocturnal searches with vehicles and daytime ground searches, keying on postpartum behavior of females as indicators of parturition or presence of neonates (Downing and McGinnes 1969, White et al. 1972, Huegel et al. 1985). McCoy et al. (2013) took advantage of extensive navigable roads to locate and capture fawns using a thermal-imaging camera (see Ditchkoff et al. 2005 for a detailed description of this method). Unfortunately, behavior- and observation-based techniques inherently yield neonates of varying ages, unknown litter sizes, and underrepresentation of the youngest individuals, all of which complicate and potentially bias survival analyses. Researchers have attempted to provide age estimates of young ungulates via hoof growth measurements (e.g. white-tailed deer *Odocoileus virginianus*, Haugen and Speake 1958, Sams et al. 1996, Brinkman et al. 2004a; mule deer *O. hemionus*, Robinette et al. 1973), though most of the equations are inaccurate due to regional differences in growth or differences in captive and wild hoof growth (Haskell et al. 2007). Moreover, regionally derived hoof-growth equations might provide decent age estimates to be used in weekly survival estimates, but they are not

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suiting for fine-scale temporal estimates (e.g. daily intervals; Grovenburg et al. 2014).

As with many techniques in wildlife science, technology improves our estimation of true population parameters. For example, movement studies now rely on GPS-technology, whereas telemetry via triangulation was used previously. Similarly, we need to consider the value of current neonatal ungulate capture techniques (and subsequent survival estimation), given the advent of improved vaginal implant transmitters (VITs; Bowman and Jacobson 1998) that allow the finding and marking of neonates shortly after parturition.

Recently, Gilbert et al. (2014) rigorously examined the differences in survival estimates and ecological inference in a population of marked neonatal Sitka black-tailed deer *O. hemionus sitkensis*. Specifically, they quantified the effects of left truncation caused by biases associated with neonatal age at capture (i.e. some individuals die before detection, resulting in left-truncated data). Gilbert et al. (2014) captured neonates opportunistically and via VITs and discovered a 7–23% overestimation of survival to 70 days of life for fawns caught opportunistically. Additionally, they discovered that model selection and covariate coefficients were strongly influenced by left truncation, resulting in spurious ecological inference (including changes in sign and magnitude of effect; Gilbert et al. 2014). Results reported by Gilbert et al. (2014) have important implications for 2 reasons: 1) researchers and managers need accurate survival rates to make informed decisions; and 2) wildlife agencies faced with funding decisions need to know the quality of data they are getting for their investment. Further, if capture technique can have such a profound effect on survival estimation, how might it bias our understanding of mortality causes? To substantiate results reported by Gilbert et al. (2014) and to explore potential management implications related to cause-specific mortality, we manipulated a previously reported VIT-based dataset on neonatal white-tailed deer in North Carolina (Chitwood et al. 2015a) to create new datasets based on hypothetical opportunistic captures.

Material and methods

The original dataset contained 65 fawns, which included six that were captured opportunistically (Chitwood et al. 2015a). We removed those six, and using 59 fawns, we randomly assigned fawns a new age-at-capture to approximate opportunistic captures. We created three new datasets in this fashion and called them Hypothetical 1, 2 and 3, respectively. Using the known fates of fawns from the original dataset and the hypothetical age-at-capture allowed us to investigate the effects of left truncation caused by opportunistic captures. However, in the hypothetical datasets, any fawn ‘captured’ after it was actually dead was removed from the sample. For example, if Fawn 1 was depredated on day 2 of life, but the new, randomized age-at-capture was day 3 (i.e. it would have been discovered and marked opportunistically on day 3 of life), that fawn would be missed and therefore eliminated from the new dataset. We assigned random age-at-capture using a random number generator providing values from

1 to 7; thus, in our hypothetical analysis, fawns could be marked from their day of birth through 7 days of age.

We assigned ages from 1–7 days of age for our survival scenario because white-tailed deer neonatal survival studies conducted since the advent of VITs revealed a variety of reporting approaches and values for mean age-at-capture (Table 1). Studies varied from not reporting any age-at-capture metrics to reporting a mean or age range; for those that did report ages, some studies demonstrated that a few fawns can be captured well into the second week of life (Table 1). Given the variety of reporting approaches and age ranges, assigning random ages between 1 and 7 days to the hypothetical sample seemed to be a conservative, yet realistic, range of ages.

Chitwood et al. (2015a) used known-fate modeling in Program MARK (White and Burnham 1999) to calculate survival of radiocollared neonates to 16 weeks of age, and they also explored covariates in their survival models. However, our purpose in this exercise was not to statistically test for differences between the original and hypothetical datasets or to consider more complicated models with covariates; rather, we wanted to evaluate the relative magnitude of difference in the survival estimate itself and compare the relative importance of causes of mortality for the original and hypothetical datasets. Thus, we used the original fawn dataset from Chitwood et al. (2015a; excluding the six opportunistic captures) and estimated 16-week cumulative survival using the Kaplan–Meier estimator (Pollock et al. 1989). We repeated the procedure with all three hypothetical datasets, enabling us to evaluate differences in survival estimates and changes in causes of mortality. We compared the relative importance of mortality causes between hypothetical and original datasets by calculating the proportion of deaths ascribed to each known cause of mortality.

Results

Kaplan–Meier survival to 16 weeks for the original, VIT-based dataset ($n = 59$) was 0.121 ($SE = 0.043$) and all fawns were ≤ 24 h old at capture. Due to our random age assignments and the resulting left truncation of some fawns in the hypothetical datasets, our neonate samples included 31, 35 and 38 fawns in Hypothetical datasets 1, 2 and 3, respectively. The reduction in sample size in the hypothetical datasets compared to the original dataset was because some fawns’

Table 1. Reported age-at-capture for white-tailed deer fawn survival studies relying on opportunistic capture since the advent of vaginal implant transmitters (VITs).

Publication	Mean age (days)	Age range (days)
Brinkman et al. 2004b	not reported	not reported
Vreeland et al. 2004	not reported	not reported
Grovenburg et al. 2011 ^a	4.3	< 1 to 13
Grovenburg et al. 2012	1.8 ^b ; 6 ^c	not reported
McCoy et al. 2013	7.2	not reported
Duquette et al. 2014 ^d	not reported	all ≤ 15 days

^aused VITs in one year.

^bmean age for two years of study.

^cmean age for one year of study.

^dmostly opportunistic sample (100 of 129 neonates).

new age-at-capture was later than their actual death (i.e. they were dead before they were detected, Gilbert et al. 2014). Average hypothetical age-at-capture was 4.0 (SE = 0.39), 3.8 (SE = 0.36) and 3.5 (SE = 0.30) days for Hypothetical datasets 1, 2 and 3, respectively. Kaplan–Meier survival to 16 weeks of age for the hypothetical opportunistic datasets were: 1) 0.234 (SE = 0.077), 2) 0.207 (SE = 0.070) and 3) 0.191 (SE = 0.065). Hence, all three hypothetical opportunistic datasets overestimated fawn survival to 16 weeks of age.

The percentage of mortalities assigned to coyotes was greater in the hypothetical datasets when compared to the original, while starvation was substantially lower (Chitwood et al. 2015a; Table 2). In the hypothetical samples, predation (coyotes and bobcats combined) was the cause of death for 77–91% of neonates that died (Table 2); however, predation comprised 63% of mortalities in the original sample. Starvation was the second-leading cause of mortality in the original sample and it tended to have that distinction in the hypothetical samples. However, in the hypothetical samples, the relative proportion of mortalities ascribed to starvation (4–17%) was much lower than in the original sample (29%).

Discussion

The hypothetical, opportunistic datasets yielded overestimates of fawn survival compared to the original VIT-based dataset. If survival rates are the basis of a demographic analysis to be used for making decisions about managing populations (Chitwood et al. 2015b), then spurious estimates of survival that stem from left-truncated data could potentially lead to misplaced or ineffective management actions. Additionally, our exercise suggested that relying on opportunistic capture in areas with high mortality at young ages can result in many young fawns being missed, which reduces sample size at the youngest ages and diminishes power to detect important trends. Further, accounting for dependence among siblings (Bishop et al. 2008, Chitwood et al. 2015a) is more difficult because opportunistically captured individuals cannot always be linked to one another due to physical separation of the twins by the mother or death of 1 sibling at a young age (i.e. the dead 1 gets missed).

Table 2. Causes of mortality among radiocollared neonatal white-tailed deer at Fort Bragg Military Installation, North Carolina, 2011–2012. Hypothetical results represent mortality with left-truncated data from three hypothetical fawn datasets, while Original results are derived from the original dataset reported in Chitwood et al. (2015a). For each dataset, sample size (n) is the number dead from the mortality source, and the percentage (%) is the percent of all mortalities due to that mortality source.

Cause of mortality	Hypothetical datasets						Original dataset	
	1		2		3		n	%
Coyote	19	82.6	20	74.1	20	66.7	27	52.9
Starvation	1	4.3	3	11.1	5	16.7	15	29.4
Bobcat	2	8.7	3	11.1	3	10.0	5	9.8
Unknown ^a	1	4.3	1	3.7	2	6.7	3	5.9
Vehicle	0	0	0	0	0	0	1	2.0

^aincludes non-depredated, non-starved neonates.

The hypothetical samples also highlighted a potential problem with quantifying the relative importance of mortality causes, which could affect understanding of population limitation and regulation. Descriptive assessment of causes of mortality from the hypothetical sample painted a slightly different picture than what was reported by Chitwood et al. (2015a). Coyote kills were overrepresented in the hypothetical samples, though they were the leading cause of mortality in all datasets. However, starvation was an important cause of mortality in the original dataset but was of variable (and lower) importance in the hypothetical datasets (ranging from 1 death to 5, rather than 15 in the original dataset). Because all starvations in the original study occurred in the first three days of life (potentially resulting from abandonment or failure in provisioning by the dam, Chitwood et al. 2015a), opportunistic sampling of fawns likely is biased against this cause of mortality because the dead fawns would never enter the sample. Such bias has important management implications because identifying leading causes of mortality can influence management decisions about how to mitigate limiting factors. For example, predator control may be recommended when predation appears to be the most important mortality factor; however, if starvation is an important mortality source, then habitat management to improve nutritional plane (for gestating or lactating females) might be recommended. If capture method causes bias in the detection or relative importance of these two sources of mortality, then management actions may not be effective.

Capture methods themselves might also bias assignment of mortality causes. For example, the use of VITs might predispose a female to abandon her young due to human disturbance shortly after parturition, resulting in over-assignment of starvation as a cause of mortality. By contrast, reliance on opportunistic capture might predispose researchers to capture older fawns that have already survived the abandonment window immediately following birth, resulting in under-assignment of starvation as a cause of mortality. Some research indicates that risk associated with marking-induced abandonment in white-tailed deer is low and that omitting starved fawns from survival studies could underestimate natural survival rates (Carstensen Powell et al. 2005). However, a recent study of moose *Alces alces* reported post capture abandonment and used a GPS-based approach to document some of the complexities (DelGiudice et al. 2015). Indeed, additional research and the use of novel techniques for identifying and accounting for capture-related biases should continue to be important for researchers and managers, as management recommendations might be quite dependent on the relative importance of various causes of mortality.

Gilbert et al. (2014) made a compelling case for how easily fawn survival estimates and model inference could be biased when relying solely on opportunistic captures. Likewise, using our own data (Chitwood et al. 2015a) and a conservative exercise in left truncation, we demonstrated similar effects. Survival estimated from the hypothetical, opportunistic dataset was biased high and the relative importance of mortality causes changed. Just as regional comparison of fawn survival estimates might not make sense due to differences in predators, vegetative types and deer densities, comparing fawn survival estimates derived from

different methodologies might be erroneous. Moreover, making management recommendations based on biased survival estimates and a potentially inaccurate understanding of cause-specific mortality has the potential to jeopardize the resource, as well as trust among stakeholders. For example, overestimating fawn survival could lead to overestimating how much hunting mortality a deer population can withstand, which might put agencies in the awkward position of trying to explain apparent deer population declines when available data indicate they should not be declining.

Results from Gilbert et al. (2014), coupled with data presented herein, should give managers and researchers pause. First, studies of neonatal survival conducted before VITs were optimized should not be ignored; however, we should acknowledge the likelihood that their estimates are biased high due to left truncation and interpret their results and management implications with this knowledge. Second, future neonatal survival research should be evaluated under a new paradigm – one that explicitly considers potential biases associated with capture technique. Consideration of field methods should be important, particularly if neonatal survival studies are initiated in the face of public pressure and survival estimates are critical for management.

Conclusions

The purpose of this paper is to spur thought and discussion on the implications of field methodology – not to assume that results from a small sample of white-tailed deer fawns from 1 population should be applied everywhere. However, logic and empirical evidence indicate that estimating neonatal ungulate survival via opportunistic captures is biased high. Just as researchers do not condone conducting a fine-scale movement analysis based on weekly VHF triangulations, we need to recognize that new technology (i.e. VITs) has improved our ability to estimate the fawn survival parameter, increased our ability to assess dependence among known siblings, and allowed us to assign mortality causes at very young ages. The next step is making sure that capture technique (including the use of VITs) does not introduce bias into the assignment of mortality causes. We believe that researchers should continue to test how capture-related biases affect survival estimation and cause-specific mortality. We do not believe that researchers should overestimate neonatal survival just because some sampling methodologies are cheaper or easier.

Acknowledgements – We thank T. Grovenburg and S. Newey for providing helpful comments on an earlier draft of the manuscript.

Funding – We thank the United States Dept of Defense and Fort Bragg Wildlife Branch for funding.

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