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Many studies have reported estimates of crippling loss (i.e., birds shot, noticeably or not, and not retrieved) for northern bobwhites (*Colinus virginianus*); however, comparisons among studies have been difficult because of a lack of standardized definitions and methods of calculation. The purpose of this paper was to: 1) provide a review of crippling loss of bobwhites across their geographic range, and 2) develop terminology that allowed for explicit discussion of crippling loss and facilitated comparison among studies. We also obtained an estimate of crippling loss for bobwhites in southern Texas using data from a larger study investigating the effects of ranch-road baiting on bobwhites. Reported estimates of crippling loss ranged from 5 to 31% of recorded harvest and 5-24% of total kill. We propose that studies reporting crippling loss use explicit definitions including those developed herein, allowing for inter-study comparisons. Documenting crippling loss in the field should include monitoring of radio-marked bobwhites the morning after a hunt to correctly identify crippled loss birds. In addition, practices (e.g., amount of time spent looking for downed birds) potentially minimizing crippling loss on harvested bobwhite populations should be identified.

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Introduction

Despite the occurrence of crippling loss during harvest, many studies discussing bobwhite harvest mortality have failed to mention crippling loss in their estimates of harvest rates (Vance and Ellis 1972, Hurst and Warren 1982) or cause-specific mortality (Curtis et al. 1989, Robinette and Doerr 1993, Dixon et al. 1996, Williams et al. 2000, Madison et al. 2002). These studies either did not consider crippling loss significant to their analysis, had no crippling loss to report, or included crippling loss within their estimate of harvest rate but did not report it. If crippling loss was included in these estimates but not mentioned, no specification was given as to what percentage of harvested bobwhites represented birds lost to crippling.

The purpose of this paper was to 1) provide a review and comparison of crippling loss of bobwhites across their geographic range using standardized terminology, and 2) develop terminology that allows for explicit discussion of crippling loss and facilitates comparisons among studies. We also provide an estimate of crippling loss for bobwhites in southern Texas obtained from data gathered as part of a larger study investigating the effects of ranch-road baiting on bobwhites (Haines et al. 2004).

Methods

We conducted a literature review of bobwhite studies which specifically reported crippling loss as a cause-specific mortality. We summarized crippling loss for bobwhites in tabular form by region.

Crippling Loss Estimate

We obtained an estimate of crippling loss for southern Texas on a private ranch located 8 km east of Hebbronville, Texas in Jim Hogg County. The study area is contained within the Rio Grande Plains ecoregion (Gould 1975). Annual rainfall ranges from 35 to 66 cm and soils range from clays to sandy loams (Correll and Johnston 1979). Haines et al. (2004) provided a more complete description of the study area.

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We trapped bobwhites from mid-August through September 2001 and 2002 using funnel traps baited with milo (Stoddard 1931, pp. 442-445) and by night-netting roosting coveys (Labisky 1968) during November through January 2001-2002 and 2002-2003. We banded all captured bobwhites and radiocollared any bobwhite weighing $\geq$150 g. We fitted bobwhites with 6 to 7g neck-loop radiotransmitters (American Wildlife Enterprises, Tallahassee, Florida). We monitored each radiomarked bobwhite 5 times a week to determine cause-specific mortality. Bobwhites were found by homing (White and Garrott 1990, Stauffer 1993). We categorized bobwhite mortality as predation or harvest following the criteria of Carter et al. (2002). We defined crippling loss as any radio-marked bobwhite found dead and intact (i.e., not depredated or scavenged) following a hunt. We monitored radiomarked bobwhites within 2-48 hours following a hunt. We confirmed crippling loss by removing the feathers from the body of the recovered bobwhites and documenting the presence of shotgun pellet wounds.

Results

Literature Review

The interpretation of what constitutes crippling loss, and therefore its calculation varied across studies (Table 1). Bennit (1945) defined crippling loss as the number of birds that were shot but unretrieved from the field, whereas Kellogg and Doster (1971) not only included the number of birds that were shot and unretrieved, but also the number of birds that were "feathered" by shot but continued to fly. Parry et al. (1997) defined crippling loss as the number of birds found in the field dead from pellet wounds (via radiotelemetry) post-hunt. The calculation of crippling loss has also varied among studies, being calculated either as a proportion of retrieved birds (e.g., Bennit 1945, Suchy and Munkel 2000) or as a proportion of total kill (retrieved + unretrieved; e.g. Parry et al. 1997, Lehmann 1984).

Crippling Loss Estimate

We captured and radiomarked 150 bobwhites from mid-August to January 2001-2002 and 2002-2003. We documented 53 mortalities of radiomarked birds, of which 34 (65.4%) were depredated, 18 (32.7%) were harvested, and 1 (1.9%) died of unknown causes. Of the 18 harvested bobwhites, 12 were retrieved and 6 were unretrieved (found via radiotelemetry). Thus, crippling loss represented 50% (6/12) of retrieved harvest and 33% (6/18) of total kill. Of the 6 crippled losses, 1 represented a bobwhite which was noticeably shot but survived. This radio-marked bobwhite was shot through the wing at the base of the primary feathers and lost the ability to fly. It survived 7-9 days in the field after being shot until it was eventually depredated. Exclusive of our crippling loss estimates, reported estimates for crippling loss in the literature ranged from 5-31% of retrieved harvest and from 5-24% of total kill (Table 1).

Discussion

Definitions

When defining crippling loss we are interested on how it impacts the total mortality rate due to harvest in the absence of natural mortality. Thus, we suggest representing all hunting-related mortality occurring from start to end of a hunting period, including both retrieved and unretrieved animals, as H_o. We express H_o as

$$H_o = H_r + H_l + H_f + H_w \quad \text{(Equation 1)}$$

where

H_r = mortality rate of harvested animals noticeably shot, downed, and retrieved (i.e., "bagged"; retrieval rates),

H_l = mortality rate of harvested animals noticeably shot, downed, but not retrieved (i.e., lost),

H_f = mortality rate of animals noticeably shot but not downed (i.e., "feathered"), not retrieved, and subsequently dead as a result of shot wounds,

H_w = mortality rate of animals not noticeably shot, not downed, not retrieved, and subsequently died as a result of shot wounds.

Three of the variables (H_r, H_l, and H_f) can be read-

Table 1: Summary of published studies reporting percentage of crippling loss for northern bobwhite.

Studies by region	Location of study	Retrieved harvest	Reported crippled	Total harvest	Crippling loss (%) of retrieved harvest	Crippling loss (%) of total harvest
Southeast						
Gehrken (1956:241)	Southeast Virginia	NR[c]	NR	NR	10.7[d]	NA[f]
Rosene (1969:185)	South Carolina	500	100	600	20	16.7
Kellog and Doster (1971:148)[a]	Florida	846	266	1,112	31.4	23.9
Doster et al. (1982:47)	Florida	2,245	615	2,860	27.4	21.5
Lehmann (1984:304)	Georgia	8,187	431	8,618	5.3	5
Mid-west						
Bennitt (1945)	Missouri (Metropolitan hunters)	NR	NR	NR	8.7[e]	NA
Bennitt (1945)	Missouri (Other hunters)	NR	NR	NR	7.4[e]	NA
Hood (1955:16)[a]	Mississippi	535	135	670	25.2	20.1
Roseberry and Klimstra (1984:41)	Illinois	2,893	349	3,242	12.1	10.8
Suchy and Munkel (2000)	South-central Iowa (BSSA)	NR	NR	NR	28	NA
Suchy and Munkel (2000)	South-central Iowa (MSA)	NR	NR	NR	17	NA
Burger et al. (1995:405)	Missouri	121	28	149	23.1	18.8
Southwest						
Parmalee (1953:343)	East-central Texas	243	64	307	26.3	20.8
Snyder (1978:34)	Colorado	1,535	242	1,755	16	13.8
Shupe et al. (1990:24)	South Texas	NR	NR	NR	NA	15.1
Parry et al. (1997)	W. Oklahoma (hunter reported)	5,108	805	5,913	15.8	13.6
Parry et al. (1997)	W. Oklahoma (radiomarked)	150	20	170	13.3	11.8
Haines (2004)[b]	S. Texas	12	6	18	50	33.3

[a] crippled estimate includes both 1) bobwhites downed but not retrieved and 2) feathered and not retrieved; Kellog and Doster (1971; 109 + 157, respectively) and Hood (1955; 57 + 87, respectively).
[b] crippled estimate includes 5 bobwhites downed but not retrieved and 1 bobwhite noticeably shot but dying 7-9 days later presumably from predation.
[d] referenced as % shot and lost; presumed of harvested birds and not total kill.
[e] referenced as % of bag shot down but lost; presumed of harvested birds and not total kill.
[f] not applicable.

ily estimated from harvest data, provided these data are recorded in the field. The fourth variable, H_w, is more difficult to measure but can be estimated with the aid of radiotelemetry. It is important to note that the latter 3 parameters of Equation (1) constitute all the variables contributing to crippling loss; thus crippling loss rate can be expressed as

$C = H_l + H_f + H_w$ (Equation 2),

and harvest rate (H_o) in Equation (1) can be simplified to

$H_o = H_r + C$ (Equation 3).

Crippling loss proportions can be calculated as a proportion of retrieved birds, as a proportion of total kill, or as a proportion of the prehunt population (N_f). These estimates are calculated as

$C_r = C / H_r$ (Equation 4),

$C_k = C / H_o$ (Equation 5),

and

$C_n = C / N_f$ (Equation 6),

respectively. Only the former 2 definitions of crippling loss (i.e., C_r and C_k) have been reported in the literature.

Crippling Loss Estimate

Our field estimates of crippling loss, whether in reference to retrieved harvest or total kill, were higher than estimates reported in the literature (Table 1). Our higher estimates of crippling loss may be consequences of inadequate sample size, low harvest rate, and/or our radiomonitoring of bobwhites 2-48 hours following hunts. The rather "immediate" monitoring of radio-marked bobwhites after a hunt might have provided us with a more accurate depiction of actual crippling loss, as bobwhites that would have been misclassified as "depredated" in a less timely schedule would be correctly classified as "crippled loss". However, because monitoring took place 2-48 post hunt our estimates of crippling loss could still potentially be low, with birds being lost to scavengers. In addition, Parry et al. (1997) located radio-marked bobwhites the morning after a hunt and documented no difference between hunter-reported and radiotelemetry-generated estimates of crippling loss (Table 1). However, we could not compare between hunter-reported and radiotelemetry-generated estimates of crippling loss because the landowner of our study site did not keep records of unretrieved or feathered birds.

The protocol of Parry et al. (1997) to monitor bobwhites the day after a hunt represents a good approach to document crippling loss in harvested populations. However, we propose that monitoring of radio-marked bobwhites should continue on a daily basis beyond 1-day post hunt because birds that were crippled but survived >1 day may be classified incorrectly, as these handicapped birds would not be found dead until they succumbed to injuries or were subsequently depredated. Bobwhites that were shot but only crippled are more susceptible to predation (Curtis et al. 1989, Suchy and Munkel 2000). We documented this for the bobwhite that was shot through the wing but still managed to survive an additional 7-9 days after the hunt. In addition, we recommend more research to validate the findings of Parry et al. (1997) that there was no difference between hunter-reported and radiotelemetry-generated estimates of crippling loss.

Suggestions

We propose that studies reporting crippling loss use terminology which explicitly specifies the type of crippling loss being calculated (i.e., proportion crippling loss of retrieved harvest, of total kill, or of prehunt population) as well as report its composition. This information then could be used to more accurately compare among studies and allow for better evaluation of the effects of harvest on bobwhite populations (Pollock et al. 1989, Roseberry 1979, Roseberry and Klimstra 1984).

Crippling loss could substantially change the estimation of harvest impacts on wild bobwhite populations, especially if harvest rates did not account for this added mortality. Practices that are most effective at mitigating crippling loss (e.g., skill of hunter, dog training, number of hunters in a party, amount of time spent looking for downed birds, tighter grouping of pellet shot, etc.) should be identified. In addition, future research should be con-

ducted to model the impacts of crippling loss on harvested bobwhite population dynamics, to measure the impacts of hunting with and without measured crippling loss, and to measure the impacts of crippling loss at varying levels of harvest effort.

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