The Use of Cripples/Hit Versus Cripples/Shot in Comparing Wounding Losses for Lead and Steel Shot

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Abstract: Two definitions of crippling rate, cripples/shot and cripples/hit, have been employed in field studies to compare waterfowl wounding losses for lead and steel shot. Properties of these 2 definitions were compared using the Louisiana Lacassine Study data (Hebert et al. 1982) and a mathematical model. Cripples/shot was shown to decrease to a limit of 0 with an increase in misses even though the actual number of cripples remains constant. Cripples/shot, and not cripples/hit, was subject to an interaction between load and distance. The susceptibility of cripples/shot to an interaction between load and distance may result in the conclusion of no significant difference in crippling rates for the loads, regardless of what the actual relative wounding losses might be. Cripples/hit was more reliable than cripples/shot for comparing wounding losses for lead and steel shot.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 37:79–85

In recent years increasing concern has been expressed over the mortality of waterfowl due to the ingestion of lead shot. A remedy advocated for this problem is the substitution of steel shot for lead shot. Questions concerning the comparative crippling rates of lead versus steel shot have led to comparisons of the efficiency of lead versus steel shot for waterfowl hunting. One problem encountered in attempting to compare the results of the various studies has been the differing definitions of crippling rate. The purpose of this paper is to compare 2 definitions of crippling rate, cripples/hit and cripples/shot, which have been employed to estimate the relative wounding losses for lead versus steel shot.

Methods

The Louisiana Lacassine Study data and a mathematical model were used to compare the cripples/hit and cripples/shot definitions of crippling rate.

Discussion

The definition of crippling rate employed in the Louisiana Lacassine Study was cripples/hit, with hits = cripples + bagged, as opposed to the definition cripples/shot reported in the California Tule Lake (Smith and Roster 1979) and the Missouri Schell-Osage (Humburg et al. 1982) studies. One difference between these 2 definitions of crippling rate is that cripples/shot, and not cripples/hit, is biased by misses in that if more shots are made with no hits, cripples/shot decreases to a limit of 0.

To facilitate an explanation of the relationship between these 2 definitions of crippling rate, it should be noted that

$$\text{cripples/shot} = \text{cripples/hit} \times \text{hits/shot}.$$

That is, the variable cripples/shot is the product of the 2 independent variables, hits/shot and cripples/hit, the latter being conditional on a hit. This expression suggests that for an increase in the number of shots with no hits (all misses), cripples/shot decreases to a limit of O, whereas cripples/hit remains constant (Table 1). Thus, cripples/shot decreases with an increase in misses, even though the actual number of cripples remains constant.

A comparison of cripples/hit and cripples/shot was made using the raw data from the Lacassine Study, (Hebert et al. 1982), summarized in Tables 2, 3, and 4. To compare the number of ducks crippled for the same number of ducks bagged, assuming the cripples/shot, cripples/hit, and hits/shot rates did not change for either load, the total number of shots fired, shots missed, ducks hit, ducks bagged, and ducks crippled for steel shot in Table 2 were increased by 26% in order to have the same number (1,242) bagged for both loads. The cripples/shot rates are 4.6% for lead shot and 5.1% for steel shot. If the crippling rate is defined to be cripples/shot, the crippling rate is estimated to be 10.9% greater for steel than for lead shot, even though the actual number of ducks crippled is projected to be 50% greater for steel than for lead shot. Thus, for this example, cripples/shot appears to grossly underestimate the actual relative wounding losses for the 2 loads.

The cripples/hit rates in Table 2 are 22.8% for lead shot and 30.7% for steel shot, resulting in a 34.6% relative increase in crippling rate for steel

Table 1. Example of decreasing property of cripples/shot for an increase in number of misses with a constant number of cripples.

Shots	Hits	Cripples	Cripples/hit	Cripples/shot
10	4	2	0.5	0.2
20	4	2	0.5	0.1
50	4	2	0.5	0.04
100	4	2	0.5	0.02
1,000	4	2	0.5	0.002

Table 2. Total number of shots fired, shots missed, ducks hit, bagged, and crippled with resulting hits/shot, cripples/hit, and cripples/shot for each load for all distances in the Lacassine Study (Hebert et al. 1982), with projected values for equal number of ducks bagged.

	Lead[a]	Steel[a]	Percent difference[a]	Steel[b]	Percent difference[b]
Shots fired	8,023	8,615	7.4	10,852	35.3
Shots missed	6,415	7,193	12.1	9,061	41.2
Ducks hit	1,608	1,422	–11.6	1,791	11.4
Ducks bagged	1,242	986	–20.6	1,242	0.0
Ducks crippled	366	436	19.1	549	50.0
Hits/shot	0.200	0.165	–17.5	0.165	–17.5
Cripples/hit	0.228	0.307	34.6	0.307	34.6
Cripples/shot	0.046	0.051	10.9	0.051	10.9

[a] Observed values.
[b] Projected values for equal number of ducks bagged.

over lead shot. Thus, for this example, the cripples/hit definition of crippling rate also underestimates the actual relative wounding losses for the 2 loads, but cripples/hit provides a considerably more accurate estimate than crip-les/shot.

Two other comparisons of cripples/hit and cripples/shot were made using the raw data from the Lacassine Study by considering the data separately for distances less than or equal to 32 m and distances greater than 32 m. To compare the number of ducks crippled for the same number of ducks bagged, computations similar to those made for the total data were made. For distances less than or equal to 32 m, the entries for steel shot in Table 3 were

Table 3. Total number of shots fired, shots missed, ducks hit, bagged, and crippled with resulting hits/shot, cripples/hit, and cripples/shot for each load for distances ≤32 m in the Lacassine Study (Hebert et al. 1982), with projected values for equal number of ducks bagged.

	Lead[a]	Steel[a]	Percent difference[a]	Steel[b]	Percent difference[b]
Shots fired	4,035	4,348	7.8	5,244	30.0
Shots missed	2,969	3,351	12.9	4,042	36.1
Ducks hit	1,066	997	–6.5	1,202	12.8
Ducks bagged	878	728	–17.1	878	0.0
Ducks crippled	188	269	43.1	324	72.3
Hits/shot	0.264	0.229	–13.3	0.229	–13.3
Cripples/hit	0.176	0.270	52.9	0.270	52.9
Cripples/shot	0.047	0.062	32.8	0.062	32.8

[a] Observed values.
[b] Projected values for equal number of ducks bagged.

increased by 20.6% in order to have the same number (878) bagged for both loads. The cripples/shot rates are 4.7% for lead shot and 6.2% for steel shot, resulting in an estimated 32.8% increase in crippling rate for steel over lead shot. This increase in cripples/shot again grossly underestimates the projected 72.3% increase in actual number of ducks crippled by steel over lead shot. Compared with the 52.9% increase in cripples/hit for steel over lead shot, which again underestimates the actual relative wounding losses for the 2 loads, cripples/hit again provides a more accurate estimate than cripples/shot.

For the third example using the Lacassine data, the entries for steel shot in Table 4 for distances greater than 32 m were increased by 41.1% in order to have the same number bagged (364) for both loads. The cripples/shot rates are 4.5% for lead shot and 3.9% for steel shot. Thus, for this example, if the crippling rate is defined to be cripples/shot, the crippling rate is estimated to be 12.3% less for steel than for lead shot. This is even though the actual number of ducks crippled is projected to be 32.4% greater for steel than for lead shot. For this example then, cripples/shot incorrectly indicates a decrease in crippling rate for steel over lead shot, whereas the actual relative wounding losses are greater for steel than for lead shot. In comparison, there is a 19.6% increase in cripples/hit for steel over lead shot. Although cripples/hit correctly indicates an increase in the wounding losses for steel over lead shot, cripples/hit again underestimates the projected relative increase in actual number of ducks crippled.

Another property of cripples/shot is the possibility of an interaction between load and distance, as was the case for the Lacassine data. Analyses of the Lacassine data verified that hits/shot decreased and cripples/hit increased for both loads with increasing distance (Table 5), with no significant

Table 4. Total number of shots fired, shots missed, ducks hit, bagged, and crippled with resulting hits/shot, cripples/hit, and cripples/shot for each load for distances >32 m in the Lacassine Study (Hebert et al. 1982), with projected values for equal number of ducks bagged.

	Lead[a]	Steel[a]	Percent difference[a]	Steel[b]	Percent difference[b]
Shots fired	3,988	4,267	7.0	6,020	51.0
Shots missed	3,446	3,842	11.5	5,420	57.3
Ducks hit	542	425	−21.6	600	10.6
Ducks bagged	364	258	−29.1	364	0.0
Ducks crippled	178	167	−6.2	236	32.4
Hits/shot	0.136	0.100	−26.5	0.100	−26.5
Cripples/hit	0.328	0.393	19.6	0.393	19.6
Cripples/shot	0.045	0.039	−12.3	0.039	−12.3

[a] Observed values.
[b] Projected values for equal number of ducks bagged.

Table 5. Means for hits/shot, cripples/hit, and cripples/shot observed in the Lacassine Study (Hebert et al. 1982).

Distance (meters)	Means[a]		
	Hits/shot	Cripples/hit	Cripples/shot
		No. 6 lead	
≤32	0.264	0.166	0.043
>32	0.139	0.334	0.045
All distances	0.201	0.250	0.044
		No. 4 steel	
≤32	0.234	0.272	0.063
>32	0.098	0.413	0.039
All distances	0.166	0.342	0.051

[a] Unweighted means of actual observations (by blind) whereas back-transformed means were reported in the Lacassine Study.

($P > 0.09$) interaction between load and distance for either cripples/hit or hits/shot (Herbert et al. 1982). These analyses also verified a significant ($P = 0.0008$) increase in cripples/hit and a significant ($P = 0.0001$) decrease in hits/shot for steel over lead shot. Consider the effect on cripples/shot as either cripples/hit or hits/shot increases or decreases, and in particular as 1 factor increases and the other decreases. The average of their product, cripples/shot, may approach a constant and therefore may not result in a useful estimate of the relative wounding losses for different loads. Cripples/shot means were relatively constant (4-5%) for the different loads tested in the 2 most extensive field studies completed to date for ducks, Schell-Osage 1979 and Lacassine 1980 to 1981.

Upon analysis of the Lacassine data using the cripples/shot definition, a significant ($P = 0.001$) interaction between load and distance was found, with no significant ($P = 0.109$) overall difference between the steel shot and lead shot loads. The interaction between load and distance is apparent in that cripples/shot increased slightly for lead shot with increasing distance, whereas it decreased for steel shot (Table 5). Moreover, cripples/shot for lead shot was lower than for steel shot at the shorter distances, whereas it was slightly higher for lead than for steel shot at the greater distances. This leads to the conclusion of no significant overall difference between the 2 loads for cripples/shot, if the interaction is ignored.

A mathematical model (Fig. 1) will be used to further explain why an interaction between load and distance for cripples/shot, as observed for the Lacassine data, may occur. The model will also help explain some possible consequences of this interaction. For the purposes of this example, it will be assumed that cripples/hit is an increasing linear function and hits/shot is a decreasing linear function of distance with values from 0 to 1 (0 to 100%),

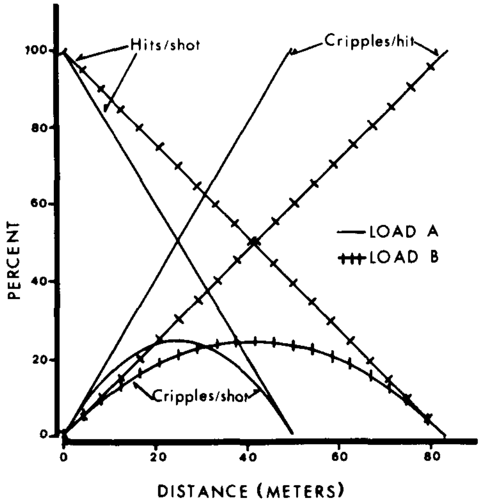

Figure 1. Mathematical model of cripples/hit and hits/shot as assumed linear functions of distance with the resulting cripples/shot quadratic functions of distance.

Load A	Load B
Cripples/hit = Distance/50	Cripples/hit = Distance/80
Hits/shot = 1-(Distance/50)	Hits/shot = 1-(Distance/80)
Cripples/shot = (Distance/50) [1-(Distance/50)]	Cripples/shot = (Distance/80) [1-(Distance/80)]

which the Lacassine data would appear to support as a reasonable beginning assumption. Also, the 2 loads to be compared will be assumed to differ in effective range. For the purposes of this discussion, the effective range for a load will be defined to be the maximum distance at which a cripple and a hit occur. The common domain of the 3 functions, cripples/shot, cripples/hit, and hits/shot, for a particular load will be assumed to be the positive distances less than the load's effective range.

In this example (Fig. 1), 50 m has arbitrarily been chosen as the effective range for Load A, and 80 m for Load B, although the results are in general the same for any 2 effective ranges (with the assumed linear constraints on cripples/hit and hits/shot). This is the case since the product of any increasing linear function and the corresponding decreasing linear function which vary in value from 0 to 1 over the same domain is a quadratic function which varies in value from 0 to 0.25. That is, regardless of the particular effective range chosen, cripples/shot necessarily varies in value from a minimum of 0 to a maximum of 0.25, since cripples/shot is the product of cripples/hit and hits/shot. Thus the graphs of the cripples/shot quadratic functions are parabolas with vertices at the same height of 0.25 (Fig. 1).

Thus, in this example illustrating a situation where the increasing cripples/hit ratio for Load A is greater than that for Load B, and the decreasing hits/shot ratio for Load A is less than that for Load B (for all positive distances less than the effective range of Load A), their products result in cripples/shot expressed as quadratic functions of distance. In contrast to cripples/hit being an increasing function from 0 to 1 for each load, cripples/shot increases to a maximum of only 0.25, attained at exactly half the effective range, and decreases thereafter to 0 at the effective range.

Also, in contrast to cripples/hit being greater for Load A than for Load B for all positive distances (where defined), cripples/shot is greater for Load A than for Load B only at the shorter distances (less than about 31 m), and is smaller at the greater distances (Fig. 1). This follows since the parabolas cross at about 31 m, which represents the interaction between load and distance for cripples/shot. Because of the nature of the interaction between load and distance for cripples/shot (Fig. 1), it is not surprising why the mean cripples/shot for Load A might not differ significantly from that for Load B, regardless of what the actual relative wounding losses might be. Also, the earlier mentioned decreasing property of cripples/shot is observed to occur with an increase in misses at the greater distances (Fig. 1).

Conclusions

Cripples/hit appears to be more reliable than cripples/shot for estimating the relative wounding losses for lead versus steel shot. Cripples/shot was found to have certain undesirable properties, not found for cripples/hit, which make results subject to misinterpretation. Cripples/shot is biased by misses in that if more shots are made with no hits, cripples/shot decreases to a limit of 0. Also, the susceptibility of cripples/shot to an interaction between load and distance may result in the conclusion of no significant difference in crippling rates for the loads, regardless of what the actual relative wounding losses might be.

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