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Source: Journal of Wildlife Diseases, 57(3) : 718-721

Published By: Wildlife Disease Association

URL: https://doi.org/10.7589/JWD-D-20-00216

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DOI: 10.7589/JWD-D-20-00216

Journal of Wildlife Diseases, 57(3), 2021, pp. 718–721
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Inferring Chronic Wasting Disease Incidence from Prevalence Data

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ABSTRACT: Incidence of chronic wasting disease infection showed strong, positive correlation ($r \geq 0.944$) with apparent prevalence among female and male mule deer (*Odocoileus hemionus*) in seven herds previously studied in Colorado and Wyoming, US. With attention to monitoring method consistency and context, inferring that observed prevalence trends reflect underlying epidemic dynamics in mule deer herds appears justifiable.

Measures of disease occurrence—especially prevalence and incidence—provide a foundation for understanding trends and effects of intervention. Wildlife disease studies tend to report apparent prevalence, the readily measured proportion of animals detected as infected among those sampled at a point in time, despite its epidemiologic limitations. Apparent prevalence serves as a tangible approximation for the more elusive measure of the true proportion infected. Detection method and sampling framework affect the exact relationship between apparent and true prevalence. Incidence gauges disease dynamics more directly than prevalence does, by measuring the rate of new infections during a reference period. However, meeting the general requirement for at least two sampling occasions per individual presents challenges in natural systems. Although not interchangeable, prevalence (P) and incidence (I) do represent "two sides of the same coin," related through the disease's expected duration in infected individuals (D), such that $P \approx ID$ in a steady-state system (Freeman and Hutchison 1980).

Measuring and comparing prevalence trends within and among affected cervid herds has yielded arguably valuable insights into the epidemiology of chronic wasting disease (CWD; Williams and Young 1980). This infectious prion disease occurs primarily in deer (*Odocoileus* spp.) and wapiti (*Cervus canadensis*) in multiple foci, including some in Colorado and neighboring Wyoming, US, that have been monitored for more than two decades (Williams and Young 1992; Miller et al. 2000, 2020). Early analyses of prevalence data revealed differences among host species and among affected herds, likely patterns of temporospatial expansion, epidemic trends over time, and, unexpected but consistently observed, differences between mule deer (*Odocoileus hemionus*) sex and age classes (Miller et al. 2000; Miller and Conner 2005). Recently, prevalence trends have been used in assessing the potential effectiveness of measures for controlling CWD in natural systems (Conner et al. 2007; Manjerovic et al. 2014; Wolfe et al. 2018; Miller et al. 2020).

An assumed relationship between CWD prevalence and incidence underpins practical application of such findings. Changes in apparent prevalence have been inferred as reflecting parallel changes in underlying CWD incidence. Responding to a reviewer's fair question about the basis for such assumptions, Miller et al. (2020) posited that "chronic wasting disease prevalence and incidence show positive correlation across a wide range of values in field studies where both parameters were measured in the same mule deer herd..." (p. 787). This *Letter* expands upon that summation, detailing the observed relationship between CWD prevalence and incidence using published and unpublished field data from infected mule deer herds.

Chronic wasting disease prevalence and incidence were reported previously in six mule deer herds located in northcentral Colorado or southeast Wyoming (Miller et al. 2008; Geremia et al. 2015; DeVivo et al. 2017; Table 1). Although Wolfe et al. (2018) reported prevalence but not incidence in a seventh herd, data from 264 adult deer sampled on two or more occasions during their field study were available to calculate incidence (no. positive/total

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TABLE 1. Chronic wasting disease prevalence and incidence among mule deer (*Odocoileus hemionus*) herds previously studied in Colorado (CO) and Wyoming (WY), USA. nd indicates not done.

Herd	Females		Males		Study
	Prevalence[a] (%)	Incidence[a]	Prevalence[a] (%)	Incidence[a]	
Estes Park, CO (before)[b]	3.7	0.043[c]	12.9	0.093[c]	Wolfe et al. 2018
Estes Park, CO (after)[b]	4.6	0.055[c]	6.4	0.045[c]	Wolfe et al. 2018
South Converse, WY	18.0	0.260	43.0	0.260	DeVivo et al. 2017
Table Mesa, CO	20.0	0.190	41.0	0.360	Miller et al. 2008
Big Hole, CO	7.0	0.040	nd	nd	Geremia et al. 2015
Cherokee Park, CO	3.0	0.020	nd	nd	Geremia et al. 2015
Campbell Valley, CO	3.0	0.005	nd	nd	Geremia et al. 2015
Red Mountain, CO	6.0	0.070	nd	nd	Geremia et al. 2015

[a] Prevalence=(positive×total deer^{-1}×100); incidence=(new cases×total deer^{-1}×yr^{-1}).

[b] Data are from two 3-yr time periods, one before and the other after disease management had been applied.

[c] Not reported in the original article, but calculated from available data on deer sampled on two or more occasions. Before: females=7 new cases/163 deer×yr; males=5 new cases/54 deer×yr. After: females=16 new cases/293 deer×yr; males=3 new cases/67 deer×yr.

[deer×yr]) for the 3-yr periods before (*n*=217 deer×yr) and after (*n*=360 deer×yr) a management intervention (Table 1). All seven herds had data from female deer; three had contemporary paired observations for both sexes, and one included data from both sexes over multiyear periods before and after a management intervention (Table 1).

The incidence of new CWD infections showed strong, positive correlation (*r*=0.944) with prevalence among female mule deer across the seven herds (Fig. 1A). The correlation was equally strong (*r*=0.947) among males over a wider prevalence range (Fig. 1A). Prevalence tended to underestimate incidence slightly (~0.8×) among females and to overestimate incidence slightly (~1.4×) among males (Fig. 1A). The observation-based relationships appear somewhat closer than the 1.5–2.6× overestimate derived from

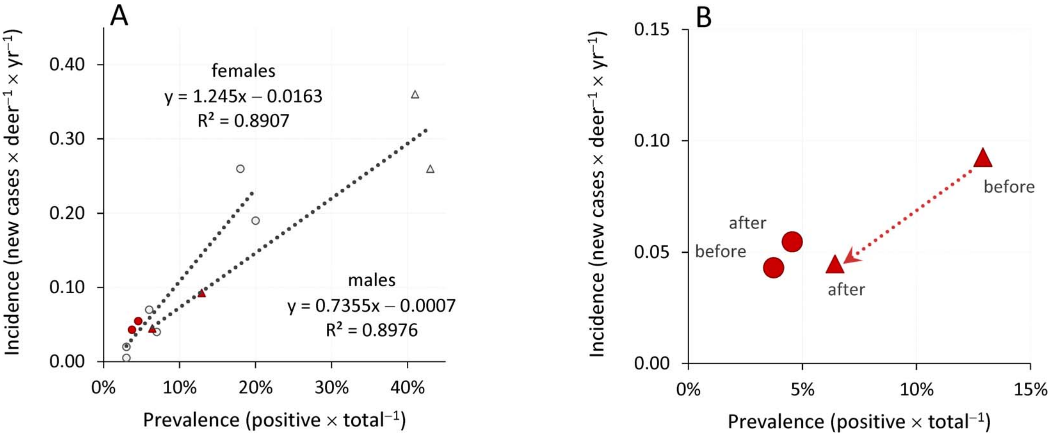

Figure 1. A. The incidence of new chronic wasting disease infections showed strong, positive correlation with prevalence among female (circles) and male (triangles) mule deer (*Odocoileus hemionus*) in herds previously studied in Colorado and Wyoming, USA. B. An observed decline in prevalence among male, but not female, deer after management intervention in the Estes Park, Colorado, study area (denoted by solid symbols on both panels; Wolfe et al. 2018), was accompanied by a measurable decline in incidence among males (arrow), but not females. See Table 1 for data sources.

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the foregoing equation using an expected duration of natural infection of 1.5–2.6 yr (Miller et al. 2008).

As a rule, prevalence exceeds incidence for chronic diseases without recovery, because cases linger in the sampled population. Following this general rule, CWD prevalence—a direct measure of active infections by virtue of diagnostics and disease traits—tended to be equal to, or greater than, incidence, especially among males when prevalence values were high (Table 1 and Fig. 1). It follows that using prevalence among adult males as an index for underlying incidence offers a conservative approach for monitoring CWD epidemic trends and responses to control efforts in mule deer. Given consistent monitoring approaches over time, increasing prevalence suggests epidemic growth within the represented demographic and decreasing prevalence suggests lowered incidence. The observed decline in CWD incidence among sampled males in apparent response to local disease management also reflected in prevalence data from the Wolfe et al. (2018) study supports such inference (Table 1 and Fig. 1B).

That said, a few provisos do apply. Whether similar relationships extend to white-tailed deer (*Odocoileus virginianus*), wapiti, or other susceptible cervid species remains to be determined. Inferences seem most appropriate for time steps of one to a few years. Moreover, care should be taken to assure observed prevalence "trends" are not merely an artifact of sampling. Comparisons made over time require careful and consistent definition of the denominator in prevalence estimation. Sampling bias should be avoided or minimized (Conner et al. 2000; Walsh 2012; WAFWA 2017). For example, given the twofold difference in prevalence among male vs. female mule deer (Miller and Conner 2005), including both sexes in estimates derived from harvest samples could significantly misrepresent trends if one sampling period included robust female harvest and the other did not. Similarly, a shift from random sampling at check stations to sampling only taxidermy submissions might misrepresent the true prevalence trend among males if mature males were only a small (but oversampled) portion of a herd's male demographic (Conner et al. 2000; Miller and Conner 2005). Changes in hunting regulations also could alter the underlying age structure of harvested animals, thereby influencing trends in apparent prevalence (Miller et al. 2020). Spatial context merits consideration as well—the data analyzed here were from relatively localized study areas, and prevalence trends measured over larger spatial scales could obscure local patterns (e.g., Miller et al. 2020). Comparing prevalence trends between herds, populations, or jurisdictions may present added challenges given greater opportunity for confounding factors (e.g., variable regulations or sampling approaches) that may influence apparent prevalence (Walsh 2012; WAFWA 2017).

With attention to monitoring methods and the context of application, inferring that observed CWD prevalence trends also reflect underlying epidemic dynamics appears justifiable. Chronic wasting disease prevalence does appear to be a reasonable index for incidence in mule deer herds across the range of values spanning those encountered in reported data sets. It follows that either declining or relatively flat prevalence trends may indeed offer encouraging evidence of short-term epidemic suppression (Manjerovic et al. 2014; Wolfe et al. 2018; Miller et al. 2020).

Supported by the Colorado Division of Parks and Wildlife. M. Conner, M. Wood, an anonymous reviewer, and the Assistant Editor provided helpful reviews of earlier drafts.

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Submitted for publication 30 November 2020.
Accepted 29 January 2021.

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