AN ASSESSMENT OF CATCH PER UNIT EFFORT TO ESTIMATE RATE OF CHANGE IN DEER AND MOOSE POPULATIONS

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ABSTRACT: Catch per unit effort (CPUE), or kills per hunter day, are often available for harvested species, and may be used to estimate population size or the finite rate of population change (λ). An assessment of the relationship between CPUE and abundance was undertaken for black-tailed deer (*Odocoileus hemionus columbianus*) and a preliminary assessment was conducted for moose (*Alces alces*). CPUE underestimated the population rate of decline and may overestimate rate of increase. Wildlife managers should not use CPUE to estimate rate of change unless the relationship between CPUE and abundance is known.

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Knowledge of population abundance, composition, and rate of change of a harvested species is often a vital prerequisite to effective management. Although numerous survey methods are available to estimate those parameters (Krebs 1989), most government agencies do not have sufficient funding to survey more than a few "key" management areas. Catch per unit effort (CPUE), or kills per hunter day, is one source of information that is often available for ungulates and may be used to estimate population size or rate of change (Crichton 1993, Lancia et al. 1996). Although several studies have shown that CPUE provides a useful index of abundance (e.g., Crête et al. 1981, Fryxell et al. 1988, Fryxell et al. 1991, Roseberry and Woolf 1991), this outcome has not always been the case (Crichton 1993, Bowyer et al. 1999).

The simplest model of the relationship between CPUE and abundance is linear proportionality,

$$CPUE_t = qN_t,$$

where q is the catchability coefficient and N_t is the density or abundance of the population (Ricker 1940). More recently, this model has been recognized as a subset of a general functional relationship of the form:

$$CPUE_t = \alpha N_t^{\beta},$$

where α is the standardized coefficient of catchability, and β is the catchability exponent (Cooke and Beddington 1985). This model acknowledges 3 possible relationships may exist between CPUE and abundance (Hilborn and Walters 1992:175), depending upon the value of β (Fig. 1). First, CPUE may stay high as abundance drops ($\beta < 1$). This situation is referred to as "hyperstability" and is expected where harvesting is highly efficient, so that most effort concentrates on the areas where animals are most abundant, and possibly because animals remain concentrated as abundance declines. Second, CPUE may be proportional to abundance ($\beta = 1$). This proportional relationship is most likely when search is random. A third possible relationship, referred to as "hyperdepletion", occurs when CPUE drops much faster than

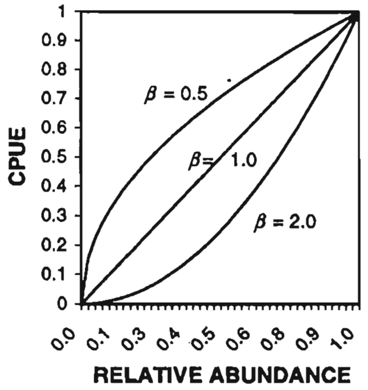

Fig. 1. Three possible relationships between abundance and CPUE including hyperstability (β = 0.5), proportionality (β = 1.0), and hyperdepletion (β=2.0) (modified from Hilborn and Walters 1992).

abundance ($\beta > 1$). This result could occur where a small, but highly vulnerable component of the population is depleted, leaving behind a less vulnerable, but still abundant population component.

Unfortunately, without independent estimates of either absolute or relative abundance, the catchability exponent cannot be estimated, and the reliability of CPUE for determining rate of change cannot be assessed. For example, if β was incorrectly assumed to be 1.0, when it was 0.5, then a measured population decline of 29% would indicate an actual decline of 50%. With random "noise" from measurement and process errors the actual difference could be much greater (de la Mare 1984, Gerrodette 1987). Factors influencing the catchability exponent for ungulates include variable weather, snow conditions, seasonal habitat shifts, or migration timing during the hunting season (Crichton 1993). Changes in the timing or length of the hunting season, changes in classes of animal hunted, and changes in access are additional factors that could bias CPUE as an index of abundance. Changes in natural predation pressures may also bias CPUE if ungulates select closed habitats when predators are common, but select open habitats where they are more easily hunted when predators are few (K. Brunt, British Columbia Ministry of Environment, Nanaimo, personal communication).

In this paper, I report on the relationship between CPUE and abundance for black-tailed deer and moose in British Columbia, and assess the utility of CPUE to estimate finite rate of change (λ). An assessment for deer was included, as there were no data sets for moose available that could provide a similar level of analysis. The assessment for moose was focused primarily on determining if the management implications of using CPUE to estimate λ for deer also were applicable to moose.

Study Area and Methods

The study area for black-tailed deer was the Nimpkish Valley, located within wildlife management unit (WMU) 1-11 on north-central Vancouver Island, British Columbia, Canada. A description of the study area and survey method is available from Jones and Mason (1983). Anecdotal data suggested the population index (deer counted/km of road searched at night using spotlights) was linearly related to absolute abundance (Harestad and Jones 1981). The deer population slowly increased during 1970-76, but declined during 1976-83 (referred to as the population-decline phase) from intensive wolf (*Canus lupus*) predation, and then increased during 1983-90 (referred to as the population-growth phase) following an intensive wolf control program (Hatter and Janz 1994). Hunter harvests were regulated through a combination of adjustments to season length and bag limits. The antlerless deer season was suspended in 1983 concurrent with the wolf-control program to assist recovery of the deer population.

The study areas for moose were 5 WMUs located in north-eastern British

Columbia, Canada. A description of the moose habitat in those areas is available from Eastman and Ritcey (1987). Each WMU was surveyed twice over a 3 - 6 year period with a stratified random-block survey design (Gasaway et al. 1986). Hunter harvests were regulated primarily through adult male (bull) seasons, although some WMUs had limited antlerless seasons. Moose numbers within each WMU were interpolated between survey years from a simple harvest model. The model iteratively fit estimates of initial population size, harvest, and adult natural mortality rate to find the minimum sum of squares between the survey and model estimates of moose abundance (Hatter 1998, 1999). Because abundance was based on interpolated values, the assessment of CPUE to estimate λ was considered preliminary for moose.

Harvest statistics for deer and moose, including total harvest, sex-and-age composition (adult male, adult female, juvenile), hunter numbers, and hunter days were estimated annually. These parameter estimates were derived from a mail-out questionnaire sent to a random sample of hunters in mid-December, with a follow-up second questionnaire sent to non-respondents. Approximately 75% of the moose hunters and 35% of the deer hunters received the questionnaire. About 65 - 70% of the hunters completed and returned the questionnaire. The CPUE for each year was estimated by calculating the following ratio

$$CPUE_t = 100 \cdot \frac{C_t}{D_t},$$

where C_t was the estimated total adult male harvest in year t, and D_t was the total effort in days.

The rate of change was estimated for deer and moose within each WMU by simple linear regression of $\log_e(N_t)$ or $\log_e(CPUE_t)$ against year (t),

$$\log_e Y_t = \log_e Y_0 + \bar{r}t + \varepsilon_t$$

(Harris 1986, Eberhardt 1987), where Y_t was either N_t (deer/km or pre-season model estimate of adult bulls) or $CPUE_t$, Y_0 was the initial estimate of N_t or $CPUE_t$, $\bar{r}$ was the observed exponential rate of change (Caughley 1977), and ε_t was the sum of the process and measurement errors. Errors were assumed to be normal, independent random variables, with mean zero and constant variance, although other error structures are possible (Gerrodette 1987, Link and Hatfield 1990). The finite rate of change (λ) is $e^{\bar{r}}$. The catchability exponent was estimated by linear regression from:

$$\log_e CPUE_t = \log_e a + b \log_e N_t$$

where a is the sample estimate of the standardized catchability coefficient α, and b is the sample estimate of the catchability exponent β.

RESULTS

Black-tailed Deer

The harvest of adult male deer (r = 0.97), hunter numbers (r=0.94), days hunted (r = 0.91), and CPUE (r = 0.94) were all correlated significantly ($P<0.05$) with deer/km during the population-decline phase (Table 1). Only the harvest of adult males (r = 0.78) and CPUE (r = 0.80) were correlated significantly ($P<0.05$) with deer/km during the population-growth phase.

Rate of change from deer/km during the population-decline phase (λ=0.78, 95% CI: 0.74 - 0.82) was significantly lower than the corresponding estimate from CPUE (λ= 0.86, 95% CI: 0.82 - 0.91, Fig. 2). Rate of change from deer/km during the population-growth phase (λ= 1.17; 95% CI: 1.12 - 1.23) was not significantly different from CPUE (λ = 1.17; 95% CI: 1.10 - 1.26). The relationship between CPUE and abundance during the population-decline phase was $\log_e CPUE_t = 0.63 + 0.58(\log_e N_t) \pm 0.12$ (r^2

Table 1. Annual hunter harvest information and population index (deer/km) for black-tailed deer from 1976 to 1990 in WMU 1-11, north-central Vancouver Island, British Columbia.

Year	[1]Hunter Harvest		Hunters	Days Hunted	CPUE	[2]Deer/km[2]
	Antlered	Antlerless				(±SE)
1976	1088	272	2659	12350	8.81	18.4(1.92)
1977	1149	261	2167	10448	11.00	17.1(1.83)
1978	1013	246	2173	11660	8.69	13.6(1.21)
1979	583	106	1819	8597	6.78	9.1(0.91)
1980	589	123	1618	9142	6.44	7.1(0.78)
1981	350	66	1185	6715	5.21	4.6(0.46)
1982	307	27	974	6359	4.83	5.4(0.71)
1983	141	0	664	4117	3.42	3.5(0.41)
1984	320	6	734	5574	5.74	4.8(0.50)
1985	200	0	674	3844	5.20	6.0(0.73)
1986	346	0	737	4584	7.54	6.1(0.72)
1987	395	0	624	4494	8.79	6.0(0.77)
1988	308	0	477	2697	11.42	7.4(0.85)
1989	489	15	687	4437	11.02	10.9(0.95)
1990	432	4	667	4192	10.31	11.9(1.04)

[1]Antlered includes adult males, antlerless are adult females and juveniles. Antlerless harvests after 1982 are believed to be due to misreporting.

[2]Data from Hatter and Janz (1994).

= 0.92, $P = 0.0002$). The relationship between CPUE and abundance during the population-growth phase was $\log_e CPUE_t = 0.30 + 0.90(\log_e N_t) \pm 0.24$ ($r^2 = 0.73$, $P = 0.007$).

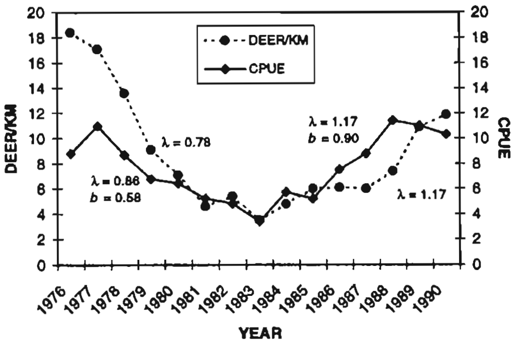

Fig. 2. Comparison of deer/km (abundance index) with CPUE (deer/100 hunter days) for black-tailed deer in WMU 1-11, north-central Vancouver Island, B.C., 1976-90. The deer population declined from 1976-83 (population-decline phase) and increased from 1983-90 (population-growth phase).

Hyperstability in CPUE occurred during the population-decline phase ($b = 0.58$, $s_b = 0.07$, 95% CI: 0.41 - 0.75; Table 2). Hyperstability was greater during the early phase of decline (1976-79; $b = 0.52$, $s_b = 0.240$) than during the latter phase (1979-83; $b = 0.68$, $s_b = 0.15$), but that difference was not significant ($P > 0.05$). CPUE was nearly proportional to abundance during the population-growth phase ($b = 0.90$, $s_b = 0.22$, 95% CI: 0.36 - 1.45). This result, however, was primarily attributed to a lack of increase in CPUE from 1988 to 1990, despite continued increases in deer abundance. Excluding those years, the catchability exponent exceeded 1.0 ($b = 1.29$, $s_b = 0.47$), but was not significantly different from unity ($P > 0.05$).

Table 2. Estimates of rate of change (λ) from abundance index and CPUE, and catchability exponent (b) for black-tailed deer in WMU 1-11, north-central Vancouver Island, British Columbia. The deer population declined from 1976-83 (population-decline phase) and increased from 1983-90 (population-growth phase).

Years	λ(Deer/km)	λ(CPUE)	b
1976-83	0.78	0.86	0.58
1983-87	1.14	1.24	1.29
1983-90	1.17	1.17	0.90

Moose

Hyperstability in CPUE was associated with declining numbers of estimated adult males. Estimates of β during periods of declining adult males ranged from $b = 0.29$ to $b = 0.55$ ($\bar{X} = 0.46$; Table 3). Estimates of β during periods of increasing bull numbers ranged from 1.29 to 1.39 ($\bar{X} = 1.34$; Table 3).

DISCUSSION

The finding of hyperstability in CPUE for declining populations of deer ($b = 0.58$) and moose ($b = 0.46$) was consistent with CPUE studies of commercial fisheries (C. J. Walters, University of British Columbia, personal communication). Walters and Pearse (1996: 32-33) estimated $b = 0.44$ for Newfoundland's northern cod (*Gadus morhua*) stock from 1960 to 1990, when the stock collapsed. They concluded "Failure to account for the possibility that $\beta < 1$, where it cannot be guaranteed to be 1.0 through the design of the abundance-indexing survey, is perhaps the most common cause of overly optimistic assessments of both stock size and uncertainty about stock size." Although evidence for hyperdepletion in CPUE for deer and moose was not statistically significant, several estimates suggested $b \geq 1$ when numbers were increasing. Thus, CPUE underestimated the population rate of decline and may overestimate the rate of increase.

Wildlife managers should not use CPUE to estimate rate of change unless the relationship between CPUE and abundance is known. If abundance estimates are available, they should be used to estimate λ, not CPUE. However, in some circumstances it may be possible to estimate β from key management areas where the relationship between CPUE and abundance has been confirmed (Hatter 1999). Abundance could then be estimated for adjacent areas where only CPUE data are available by:

$$\log_e \hat{N}_t = \frac{\log_e\left(\dfrac{CPUE_t}{a}\right)}{b}.$$

Table 3. Estimates of rate of change (λ) from abundance index and CPUE, and catchability exponent (b) for moose in 5 WMUs from north-eastern British Columbia.

WMU	Years	λ(Model)	λ(CPUE)	b
7-32	1987-91	0.84	0.92	0.55
	1993-96	1.10	1.13	1.39
7-34	1994-96	1.07	1.07	1.35
7-42	1989-93	0.81	0.94	0.29
7-44	1985-90	0.74	0.88	0.45
	1991-95	1.26	1.38	1.29
7-50	1989-92	0.85	0.91	0.53

Note that a does not need to be explicitly accounted for, as it does not influence λ. If a is included then $\hat{N}_t$ is an estimate of absolute abundance. If a is excluded then $\hat{N}_t$ is an index of abundance.

Several other studies have warned wildlife managers about assessing population trends from CPUE. Fryxell et al. (1988) cautioned that departures from linearity between population size and CPUE in Newfoundland moose might occur because of interference among hunters. Bowyer et al. (1999) reported that CPUE on Kalgin Island, Alaska initially declined with moose population size but then increased dramatically at lower population sizes. They suggested that CPUE should not be used to assess trends in moose populations without an independent measure of population size.

Mechanisms involved in hyperstability were not investigated in this study. Hunters likely concentrated their efforts, both within areas of high ungulate density and within habitats where animals were most vulnerable, as deer and moose numbers declined. Less experienced hunters with lower success rates also may have been less likely to participate when ungulate numbers were declining. Bowyer et al. (1999) hypothesized that hunters harvesting moose at low density on Kalgin Island were a more highly skilled subset of those who hunted when moose were plentiful. If managers are to fully understand the relationship between CPUE and abundance, more effort should to be directed towards understanding the functional and numerical responses of hunters to changes in ungulate density.

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