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David Fraser
Ontario Ministry of Natural Resources

James F. Gardner
Ontario Ministry of Natural Resources

George B. Kolenosky
Ontario Ministry of Natural Resources

Stewart Strathearn
Ontario Ministry of Natural Resources

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Estimation of Harvest Rate of Black Bears from Age and Sex Data

David Fraser, James F. Gardner, George B. Kolenosky, and Stewart Strathearn

Ontario Ministry of Natural Resources

Age and sex data from harvests of black bears (*Ursus americanus*) are commonly collected for management purposes. Frequently, however, the method of statistical analysis is not decided at the outset, and the data are not collected to meet the requirements of any specific technique. Subsequent analysis is often of dubious validity because important information may be biased in a manner not compatible with the type of analysis attempted. Furthermore, because most bear harvests are clearly not representative of the living population (Bunnell and Tait 1980, Gilbert et al. 1978) conventional estimates of mortality cannot normally be used (Caughley 1977), but few alternatives are available.

Most published examples of black bear data show that the ratio of males to females in the harvest declines with increasing age (Collins 1973, Lindzey and Meslow 1980, McCaffrey et al. 1976, Willey 1978; see Fig. 1). This change in the sex ratio generally has been attributed to the more rapid depletion of males as a result of their greater vulnerability to hunting (Bunnell and Tait 1980, Gilbert et al. 1978, Rogers et al. 1976). If certain assumptions can be met, appropriately collected data of this type can be analyzed by a statistical method (Paloheimo and Fraser 1981) originally developed for populations of moose (*Alces alces*). The method uses the age-related change in sex ratio to estimate the rate of harvest mortality; if the total harvest is known, then the size of the original population also can be estimated.

In this paper we discuss data requirements, assumptions, and possible sources of bias in the calculations in view of known characteristics of black bear populations. We also describe technical points that have arisen when applying the method to existing black bear data from Ontario. The paper is intended to aid a wildlife manager, preferably in consultation with a statistician, in deciding whether the method appears applicable to a particular bear population and in designing a suitable data collection.

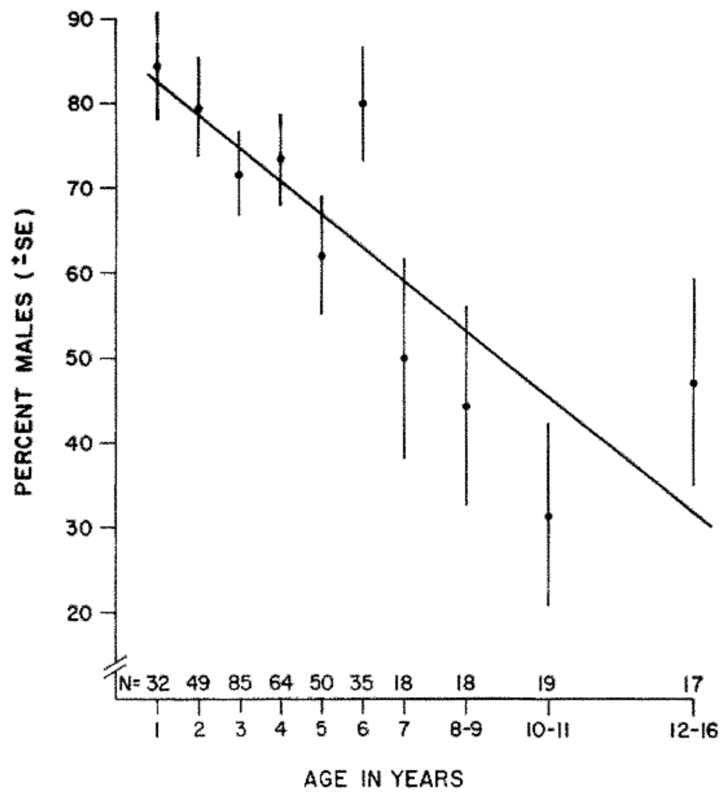
THE METHOD

The rationale of the method has been explained elsewhere (Fraser 1976, Paloheimo and Fraser 1981). Briefly, we consider a cohort that initially consists of an approximately equal number of males and females, with the males more vulnerable to harvest. In the younger age classes, males will outnumber females in the harvest. However, the higher harvest mortality of males causes their numbers to decline more rapidly with age. Although the males remain more vulnerable, the ratio of males to females in the harvest declines with age because of the progressive depletion of males (Bunnell and Tait 1980).

Estimation Procedure

In the estimation procedure, the harvest rate is divided into 2 components: p is the instantaneous harvest rate averaged for the 2 sexes, and u is a sex-specific vulnerability factor. The harvest rates for males and females are defined as ($p + u$) and ($p - u$), respectively. The ratio of males to females in the harvest at a given age is considered to be a function of p, u, the amount of harvest effort to which the cohort has been subjected since its 1st harvest, the initial sex ratio in the cohort, and the rate of nonharvest mortality for the 2 sexes. An iterative nonlinear least squares procedure is used to estimate *p*, *u*, and their variance and covariance.

Fig. 1. The percentage of males in relation to age in the black bear harvest of Kirkland Lake District, Ontario (48°N, 80°W), for 1975-79. The linear regression line was calculated with weighting according to sample size at each age. Standard errors by binomial calculations are shown for each point.



If males and females are recruited equally into the population, and if harvest effort remains constant, then a simple, approximate method may also be useful (Fraser, unpubl. data). In this method, *y* is calculated as the age at which the proportion of males in the harvest declines to 50%. The value of *y* can be estimated by linear regression of the percentage of males on age, starting at the age when sex-differential harvest begins. Then, for a range of conditions, the fraction of the population removed annually by hunting is approximately 1/*y*.

Data Requirements

Three types of data are required to estimate harvest rate.

First, a series of age-sex data is needed either from the harvest of 1 or more cohorts for a number of years or from the harvest of 1 or more years covering a range of ages. Ages are expressed in years as determined by cementum annuli (Stoneberg and Jonkel 1966).

Second, if hunting effort changes from year to year, then a measure of relative hunting effort is required for all years of hunting that influence the data. For example, the ratio of males to females at age 10 years will be influenced by the previous 9 years of hunting, and the relative effort must be known for all these years. Measures such as hunter-days per unit area are the most useful, but the calculations also can be done with subjective measures such as previous effort scaled subjectively as a proportion of the most recent year's effort.

Third, the sex ratio in the living population must be known at 1 age, preferably before the beginning of the sex-differential harvest.

In addition to the above data, the total number of harvested animals must be known if a population estimate is desired, and information on the geographic distribution of kills is useful for detecting uneven hunting pressure as discussed below.

Assumptions and Sources of Bias

The chief assumption underlying the method is that the sex-differential harvest is the only important factor causing the sex ratio to change with age. There are several possible sources of bias in bear data mostly caused by potential violations of this assumption.

The harvest data are assumed to be drawn from a population that is isolated or closed with respect to factors that would influence sex ratios. Bias would result for example, if adult animals immigrated into the collection area from an area with a different harvest rate, or if animals of 1 sex emigrated from the area more than animals of the other sex. This requires particular attention in the case of bears because adult males move over much larger areas than adult females, and subadult males are particularly prone to dispersal.

The problem can be avoided in 2 ways. A collection area could be made sufficiently large that most animals of both sexes would be permanent residents. Alternatively, if the neighboring populations have the same conditions of harvest, and if emigration and immigration balance each other, then a higher male mobility should not bias the estimates. However, the method could not be applied to a small area with a net ingress or egress of young males.

Important types of nonharvest mortality are assumed to have the same rate for the 2 sexes. In an Ontario population studied by Kolenosky (unpubl. data), capture-recapture data indicated a similar rate of natural mortality for males and females. However, deaths caused by man, such as shooting bears for crop protection or removal of animals at garbage dumps, are often biased toward males (Rogers et al. 1976) and would cause error in calculations of harvest mortality. The simplest remedy is to record age and sex data for these animals, and to include them as a component of the harvest in the calculations. In some populations, non-hunting mortality is considered slight (Lindzey and Meslow 1977), and is unlikely to bias the estimation of harvest rate.

Because the calculations normally begin at age 1 or 1.5 years, when males become more vulnerable to harvest, any sex-differential mortality before this age could bias the results. Most reported cub sex ratios are close to 50:50 (Kolenosky, unpubl. data; Lindzey and Meslow 1980; Rogers 1977), and an Ontario study showed no sex-differential mortality during the 1st year of life (Kolenosky, unpubl. data). However, in populations where early non-hunting mortality is biased toward 1 sex, the new sex ratio must be estimated at the age when the calculations begin. If cub mortality is low, or has the same rate for the 2 sexes, then an initial sex ratio of 50:50 can probably be assumed.

The differential vulnerability of males and females is assumed not to change systematically over the years of hunting represented in the data. For bears, sex-differential vulnerability is influenced by the method of hunting (Gilbert et al. 1978), the time of year (Lindzey and Meslow 1980), and perhaps by the abundance of hunters (Bunnell and Tait 1980). Therefore, results could be biased by a systematic change over years in hunting methods or the time of the hunting season, or by very large changes in hunter numbers. Problems of this type could probably be detected by examining harvest data from different years for systematic shifts in the sex ratios, especially among young adults. Older adults are less useful for this comparison because their sex ratios change more markedly in response to changes in harvest rate.

Unlike systematic changes over several years, simple fluctuations in sex-differential vulnerability will increase the variance of the estimates but should not normally cause bias. It is to be expected, for example, that the vulnerability of individual females will vary because of alternate year breeding, and that the sexes may be affected differently by fluctuations from year to year in weather, food conditions, and denning dates.

The sex-related vulnerability to hunting should not change systematically with age for the ages used in the calculation. In some sets of bear harvest data, the proportion of males increases at the oldest ages (Fig. 1). This could reflect a loss of social position by old males, and a resulting increase in vulnerability. Bias can be avoided by ending the calculations at the age when the male vulnerability factor appears to change.

Females with cubs are not harvested in some areas. This could cause the sex-related vulnerability factor to change at about age 3 when females first breed. In this case the calculations could be limited to animals of breeding age. However, the initial sex ratio (about age 3) would not be 50:50, and would have to be estimated.

TECHNICAL POINTS IN APPLYING THE METHOD TO BEAR DATA

In our attempts to apply the method to existing bear data from Ontario, 2 technical difficulties arose.

First, as is commonly observed elsewhere, Ontario black bear harvests show an under-representation of animals aged 1 or 2 years, perhaps because young bears are less vulnerable or less preferred by hunters. The statistical procedure, therefore, would yield an "average" estimate incorporating the lower harvest rates at young ages and the higher rate for older bears.

The ambiguity of this "average" estimate can be eliminated by reducing the hunting effort term for 1- and 2-year-olds by a factor corresponding to their lower vulnerability. With this adjustment the procedure would estimate the harvest rate for mature bears. Suitable vulnerability factors can be estimated by extrapolating the logarithms of age class frequencies back to the young ages in a straight line. Simulation can then be used to test whether the estimate of harvest rate is sensitive to errors in estimating these vulnerability factors. In an Ontario example we estimated that 1- and 2-year-old bears were 25 and 50% as vulnerable to harvest as animals of the same sex aged 3 years or older. Substantial differences in these estimated age-specific vulnerability factors produced very little difference in the estimated harvest rate.

Second, in remote areas with variable human access, the bear population may consist of heavily and lightly hunted segments partially mixed through movement of animals. The heavily hunted segments will, of course, be over-represented in the harvest relative to their abundance. In this case, the estimation procedure, like conventional methods of estimating mortality, will yield an "average" incorporating the higher and lower rates but biased toward the higher. Although rarely discussed, geographic variation of this type can constitute a major problem in the interpretation of wildlife harvest data, casting doubt on virtually all use of age and sex information from areas with uneven access.

The only obvious solution to this problem is more careful geographic delineation of areas with relatively even distribution of hunting effort. Accurate mapping can show whether kills are localized in more accessible areas. If so, it may be possible to do separate analyses on smaller areas where hunting is more uniformly distributed. However, the areas should not be so small that immigration or emigration of animals becomes substantial.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Because several types of data must be collected simultaneously, the method will not likely be useful for existing sets of data gathered without the specific requirements in mind. With suit-able planning, however, many agencies could probably collect appropriate data with only a moderate increase in effort. Given the confusion over bear harvest analysis (Gilbert et al. 1978) and the lack of suitable methods for estimating population sizes, the extra planning and effort might well be worthwhile.

The method will be compatible with some bear management systems, but not with all. For example, if bears are hunted in a drive, the sexes may be equally vulnerable (Hanai 1980); or if a management system involves altering the legal hunting season, then the vulnerability factor may change appreciably. In both cases, the method could not be trusted. To be most effective and compatible, methods of managing harvests and methods of collecting harvest data should be planned together as an integrated system.

The most difficult potential sources of bias in the calculations appear to be sex-differential mortality of cubs, ingress or egress of young males, and nonharvest mortality favoring 1 sex. Where the method of calculation is to be used, it would best be accompanied by research to detect and correct any bias caused by these problems.

The higher vulnerability of males is imperfectly understood. In most areas it is probably due to differences in behavior and more extensive movement patterns by males, but legal protection of breeding females, conscious selection by hunters, and later denning by males may play a role in some areas (Bunnell and Tait 1980; Gilbert et al. 1978; Kolenosky, unpubl. data; Mc- Ilroy 1972; Poelker and Hartwell 1973; Willey 1978). Better understanding of sex-differential vulnerability would allow more intelligent use of the method.

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