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ANALYSIS OF ERROR FROM CEMENTUM-ANNULI AGE ESTIMATES OF KNOWN-AGE PENNSYLVANIA BLACK BEARS

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Abstract: Cementum-annuli counts are considered the most accurate indicators of age for black bears (*Ursus americanus*), but tests of the technique have lacked large sample sizes of known-age teeth, and sources of error are not well documented. We estimated ages from cementum-annuli counts of 671 teeth from 521 Pennsylvania black bears and compared the estimated ages to their known age. We evaluated teeth aged during 1983–91 with aging criteria different from the criteria used during 1992–96, but we found no differences (M: P = 0.125; F: P = 0.748). Overall, 8.1% of the known-age teeth were aged incorrectly, and we found no differences in error distributions between sexes (P = 0.126). For both sexes, percent error increased as age class increased ($Ps \leq 0.010$). The number of incorrectly aged teeth was greater than expected ($Ps \leq 0.104$) in black bears captured during September–November (M = 11%, n = 198; F = 13%, n = 181) than during March–May (M = 3%, n = 76; F = 4%, n = 49) and June–August (M = 3%, n = 120; F = 2%, n = 45). Of 51 incorrectly aged teeth we reevaluated, 19 (37%) were aged incorrectly because of irregular tooth characteristics to which standardized aging criteria could not be applied accurately. Thirteen (25%) probably would have been aged correctly via aging criteria revised in 1992, 13 (25%) had no discernible reason for being incorrectly aged and may have been mislabeled, 5 (10%) were broken during extraction, and 1 (2%) was aged incorrectly by the tooth reader even though the annuli were normal and distinct. We concluded that counting cementum annuli is a valid technique for aging Pennsylvania black bears.

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Key words: age, black bear, cementum annuli, Pennsylvania, premolar, *Ursus americanus*.

Information on the age structure of wildlife populations is important to wildlife management and conservation efforts because survival and reproductive rates likely vary according to age, and age-structure information can provide insight into the growth of a population (Krebs 1978). Moreover, studies of life-history strategies, evolution, and population dynamics require information on age-related parameters (Gaillard et al. 1994, Newton and Rothery 1997).

Since the mid-1900s, various techniques have been used to age black bears (Coy and Garshelis 1992). Stickley (1957) correlated known black bear age with elements such as morphological development of the skull, tooth replacement and wear, and skull suture closures. Erickson et al. (1964) reported the shape and size of the skull and baculum were reliable criteria for aging male black bears. He also reported that testicle and ovary mass (when considered by season and reproductive status) were effective age indicators. In addition, Erickson et al. (1964) examined body mass, but it was not accurate for estimating age.

Biologists have analyzed cementum layers in both the canine and premolar teeth of all 3 North American bear species: black bear (Marks and Erickson 1966, Sauer et al. 1966, Stoneberg and Jonkel 1966, Willey 1974), brown bear (*Ursus arctos*; Mundy and Fuller 1964, Rausch 1969, Craighead et al. 1970, Pearson 1975), and polar bear (*Ursus maritimus*; Hensel and Sorenson 1980). Marks and Erickson (1966) concluded that counts of canine cementum annuli provided the best estimates of black bear ages, but Willey (1974) reported both the first premolar and canine teeth of black bears were equally reliable as age indicators. Coy and Garshelis (1992) summarized the history and development of using cementum annuli to age black bears.

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Each year, 2 types of cementum are produced. The very thin cementum "annulus" is formed during winter and is an acellular, darkly staining layer with a linear appearance. Darkly staining cementum resembling the annulus may be produced during other seasons, forming an "accessory line" that can potentially be misinterpreted as a cementum annulus. The abundant "light cementum" layer is produced during the growth seasons of spring, summer, and fall and is a lightly staining layer with a spongy appearance caused by its cellularity. Recently, Coy and Garshelis (1992) examined the relation between premolar cementum-annuli patterns and known reproductive histories of female black bears. The findings of Coy and Garshelis (1992) reaffirmed those reported by L. L. Rogers (Annual Meeting of the American Society of Mammalogists, Missoula, Montana, USA, 1975) that light cementum deposition is reduced during the year of cub rearing. Cementum annuli of female black bears reflect their reproductive histories (Rogers 1978, Coy and Garshelis 1992, Carrel 1994). Light cementum deposition is reduced during the year of cub rearing. The reduced amount of light cementum results in the annuli of the cubrearing year and the year after being closer together, thus "pairing" the 2 annuli. Because cubs are normally reared every other year, the alternating paired annuli are potentially distinctive indicators of the female's reproductive history. Although explanation of the physiological mechanisms underlying the formation of these patterns remains conjectural, causes of reduced cementum deposition may be related to lactation, nutrition, or behavior. Coy and Garshelis (1992) reported that the appearance of paired annuli in females signified successful cub rearing, but annuli pairing caused by cub rearing was more difficult to identify in females living in habitats with variable food resources.

Paired annuli in males are manifested by an additional dark accessory line usually deposited during summer. The accessory line is often discontinuous in teeth from young males but becomes more prominent with increasing age, until it has the same characteristics as the cementum annulus (Coy and Garshelis 1992). Older ($\geq$8 yr) male black bears killed in late summer or fall have an accessory line at the periphery of the cementum that is so prominent it could be confused with the annual cementum annulus. To correctly identify the accessory line, the reader must know the date of tooth extraction, or it could be counted incorrectly as an additional year of age. If the sex of the black bear is known, recognition of sex-specific characteristics of cementum deposition can reduce aging error. If the black bear is male, careful observation may reveal the presence of a recurring, less prominent accessory line in prior years and enable identification of the apparent paired annuli as deposited in a single year. If the black bear is female, paired annuli may be identified as indicators of cubs being reared and correctly counted as 2 years. Accessory lines are sometimes found in females and may be identified via the same criteria as for males.

To reduce subjectivity of cementum age analysis, interpretive criteria must not only be standardized in written and illustrated laboratory references, but it also must continually be tested for accuracy and precision. Evaluations that estimate accuracy and precision of the method enable users of cementum age estimates to apply them statistically with a specified level of confidence. However, there have been few attempts to analyze the degree of error in the ages estimated by cementum-annuli counts. The accuracy of cementum age estimates can only be tested using teeth of known-age black bears, but the paucity of these data continues to handicap testing efforts.

Our study of known-age Pennsylvania black bear teeth used a large sample from the same population to test aging accuracy and precision. From 1983 to 1996, the Pennsylvania Game Commission (PGC) collected first premolars from live-captured and dead Pennsylvania black bears. Our objective was to analyze error in age estimation from teeth collected from known-age black bears and processed at Matson's Laboratory (Milltown, Montana, USA). Since 1992, however, the sex-specific cementum characteristics reported by Coy and Garshelis (1992) have been used at Matson's Laboratory to estimate ages of black bears. Hence, the revised aging criteria in current use for black bears attempts to account for sex differences in cementum-annuli deposition. A comparison between teeth aged prior to 1992 and those aged after 1992 is critical to test accuracy of the different criteria used for age estimation during the 2 periods. We compared the differences in error before and after 1992, when cub-rearing years in females and prominent accessory line and annulus pairing in males were first described.

Also, we analyzed error by age, sex, and season, and we reevaluated incorrectly aged teeth to determine possible sources of error.

METHODS

Free-ranging or denning black bears were captured with Aldrich foot snares, culvert traps, or jabsticks and dart guns (Alt 1989). Black bears were immobilized with a mixture of 4.4 mg of ketamine hydrochloride and 2.2 mg of xylazine per kilogram of estimated black bear mass (Alt 1989). Recaptured black bears were identified by a numbered metal tag attached to each ear, or the inside upper lip may have been tattooed with a unique number.

Known-age black bears included those first captured as cubs (<1 yr old) or yearlings still traveling with their mother (before 1 Jul). When ≤1.5 years old, black bears can be assigned a known age by means of morphological (mass, dentition) or behavioral (traveling with mother) traits. Offspring >12 months old and traveling with the sow are yearlings because no radiocollared adult female black bear in Pennsylvania has ever remained with offspring for >1.5 years (Alt 1989). A premolar sometimes was removed from known-age black bears upon recapture (≥1 yr of age), and from most black bears killed by vehicles, legally shot during hunting season, illegally killed, or killed for other reasons (e.g., crop damage or nuisance).

We prepared tooth slides and aged all teeth at Matson's Laboratory. Teeth were cleaned, decalcified in acid, embedded in paraffin, and sectioned longitudinally at 14 microns via a rotary microtome (Humason 1972). Sections were mounted on microscope slides and stained with Giemsa stain (Stone et al. 1975). We interpreted cementum annuli of sectioned teeth via standardized cementum aging criteria under a Leitz compound microscope set for Koehler illumination (60× and 160× magnifications) (G. M. Matson. 1981. Workbook for cementum analysis, unpublished. Matson's Laboratory, Milltown, Montana, USA). After error analysis, we reevaluated tooth sections that had been incorrectly aged. G. M. Matson conducted all the initial aging, as well as all reevaluations of incorrectly aged teeth.

To estimate aging error via cementum annuli, the actual known-age for each capture or harvest in which a tooth was pulled was calculated as follows:

$$\text{Known age} = \text{tooth collection year} - \text{initial capture year} + \text{initial capture age.}$$

We grouped ages into the following age categories so that we obtained reasonable sample sizes of known-age black bears for each category: 1 year, 2 years, 3 and 4 years, and ≥5 years. We calculated error as the estimated age − known age, and termed this direct error. We distinguished direct error from a type of error we termed categorical error. Direct error was the result of calculating error before age categorization, and categorical error was the result of calculating error after age-class categorization. For example, a black bear with an estimated age of 7 years and a corresponding known-age of 6 years had a direct error of 1 year. However, that black bear had zero categorical error because both its known age and estimated age fell within the correct ≥5 category. We evaluated both types of errors because analysis of age-structure data for Pennsylvania black bears would likely group black bears according to these age categories. For males, <15% of the harvest is composed of 3- and 4-year-old black bears, and <7% is composed of ≥5-year-old black bears. For females, <30% of the harvest is composed of 3- and 4-year-old black bears, and 20% is composed of ≥5-year-old black bears (PGC, unpublished data).

Aging criteria from 1992 to 1996 differed from 1983 to 1991 because of information published by Coy and Garshelis (1992), who noted that reproductive status could affect the deposition pattern of cementum annuli in females, and they identified new aging criteria for older males. Because Alt (1989) found most female black bears in Pennsylvania produced their first litter at age 3, we used teeth from females ≥4 years old to test if aging error differed between the 2 time periods. Similarly, only teeth from males in the ≥5-year-old age class were analyzed because only the oldest black bears would have been affected by the change in aging criteria between the pre- and post-1992 periods. To test for differences in aging error resulting from changes in the aging criteria, we conducted a chi-square test of homogeneity of the distribution of errors between the pre- and post-1992 periods.

If we found no differences between the error distributions of age estimates for the pre- and post-1992 aging criteria, we pooled data to test

Table 1. The distribution of error by known age class (yr) in the estimated ages of 671 male and female black bear teeth processed by Matson's Laboratory (Milltown, Montana, USA) using cementum-annuli layer counts from known-age black bears captured in Pennsylvania, 1983–96.[a]

	1983–91 time period					1992–96 time period				
Error[b]	1 yr	2 yr	3–4 yr	≥5 yr	Total	1 yr	2 yr	3–4 yr	≥5 yr	Total
Males										
4			1	1	2					
3		1			1					
2	1		1		2	1		2		3
1	5	3	5		13	2	1			3
0	156	31	22	4	213	113	25	6	11	155
−1	1	1	1	1	3					
Females										
3								1		1
2			1		1	1	1			2
1	3		1		4	1	2			3
0	86	33	34	27	180	41	6	8	14	69
−1		1	2	5	8		1		1	2
−2			3	2	5					
−3								1		1

[a] Before 1992, paired cementum annuli in cub-rearing females were counted as complex annuli of a single year, and prominent accessory lines found in older-aged males were counted as years of age. Since 1992, the aging criteria has included the following sex-specific criteria: paired annuli in cub-rearing females have been identified as 2 separate years, and prominent accessory lines have been ignored in older-aged males.
[b] Estimated age − known age.

for differences among age and sex classes of black bears. For each sex, we used a chi-square test of homogeneity to test for differences in distributions of direct error among the 4 categories of age classes. We used the same test to test for differences in errors among age classes.

To test if errors varied depending upon the date of tooth collection, we grouped the date of tooth collection into the following 3-month periods: March–May, June–August, and September–November. We excluded teeth collected from December to February because we collected few teeth during the hibernation period. We conducted a chi-square test to examine direct error distributions among the 4 age categories during these time periods.

RESULTS

We collected and aged 671 teeth from 521 known-age black bears. The number of first premolars removed from each black bear varied from 1 to 4: 384 (74%) had 1 tooth removed, 127 (24%) had 2 removed, 7 (1%) had 3 removed, and 3 (<1%) had all 4 first premolars removed.

We found no difference in the error distributions for males or females between the 2 time periods when we used different aging criteria (M: $\chi^2_2 = 4.2$, $P = 0.125$; F: $\chi^2_2 = 1.1$, $P = 0.586$); thus, we pooled data from these 2 time periods for additional analyses. (Table 1). For females ≥4 years old, 12% ($n = 51$) were aged incorrectly during 1983–91, and 9% ($n = 22$) were aged incorrectly during 1992–96. All of the 9 incorrectly aged teeth were underestimated during 1983–91, as were both of the incorrectly aged teeth during 1992–96. For males ≥5 years old, 2 of 6 teeth were aged incorrectly during 1983–91; no teeth ($n = 11$) were aged incorrectly during 1992–96. Of the 2 incorrectly aged teeth during 1983–91, 1 was underestimated and 1 was overestimated.

Fifty-four (8.1%) of the 671 teeth were aged incorrectly, and 35 (65%) were overestimates (Table 1). Twenty-seven (9.8%) of 276 known-aged female teeth were incorrectly aged. The median error for females was 0 years, with the error ranging from −3 to 3 years. Twenty-seven (6.8%) of 395 known-age male teeth were incorrectly aged, and the median error for males was 0 years, with the error ranging from −1 to 4 years (Table 1). We found no differences in the distribution of errors among age–sex classes ($\chi^2_3 = 5.7$, $P = 0.126$).

As age increased, the percentage of teeth incorrectly aged also increased (M: $\chi^2_3 = 29.7$, $P = 0.001$; F: $\chi^2_3 = 11.5$, $P = 0.010$). However, even within the oldest age class, the overall median error was 0 years for all age–sex classes. Direct error percentages for the male age groups were 3% for the 1-year-old group, 10% for the 2-year-old group, 26% for the 3–4-year-old group, and 12% for the ≥5-year-old group. Direct error percentages for the female age groups were 4% for the 1-year-old group, 11% for the 2-year-old group, 18% for the 3–4-year-old group, and 16% for the ≥5-year-old group. For both sexes combined, direct error percentages were 3% for the 1-year-old group, 10% for the 2-year-old group, 21% for the 3–4-year-old group, and 15% for the ≥5-year-old group. Categorical error percentages corresponding to the 1, 2, 3–4, and ≥5-year-old groups were 3%, 10%, 5%, and 0% for males, and 4%, 11%, 4%, and 4% for females. For both sexes combined, categorical error percentages were 3% for the 1-year-old group, 10% for the 2-year-old group, 5% for the 3–4-year-old group, and 3% for the ≥5-year-old group.

In addition, we found seasonal differences in aging error rates among our selected 3-month periods (M: $\chi^2_4 = 12.1$, $P = 0.017$; F: $\chi^2_4 = 7.7$, $P = 0.104$). The number of incorrectly aged teeth was greater than expected in black bears captured during September–November (M = 11%, $n = 198$; F = 13%, $n = 181$). Fewer teeth were aged incorrectly than expected for teeth collected during March–May (M = 3%, $n = 76$; F = 4%, $n = 49$) and June–August (M = 3%, $n = 120$; F = 4%, $n = 45$).

We reevaluated 51 of 54 incorrectly aged tooth sections (3 slides were lost). Nineteen (37%) could not be aged via standardized aging criteria, because of irregular cementum characteristics (e.g., nonannual annuli, indistinct annuli); 13 (25%) were aged incorrectly, probably because they were aged before the Coy and Garshelis (1992) modifications to the aging criteria; 13 (25%) had no explainable errors and may have been misclassified (e.g., teeth or slides were physically switched or recorded data were incorrect); 5 (10%) were broken during extraction; and 1 (2%) was incorrectly aged, even though the annuli were normal and distinct.

DISCUSSION

McLaughlin et al. (1990) evaluated accuracy and precision of age estimates of black bears in Maine by counting cementum annuli. They tested concordance of ages estimated by experienced and inexperienced readers with 100 tooth sections selected from a black bear harvest collection, and they tested precision of age estimates with pairs of multiple teeth removed from 185 black bears. Experienced readers assigned identical age estimates to 59% of teeth in all trials, and inexperienced readers assigned identical age estimates to 31% of teeth. In addition, they found cementum age and known age agreed for 49 (88%) of 56 black bears, and that teeth from older black bears were more likely to be aged incorrectly. An additional 7 teeth (10%) were aged within ± 1 year of the true ages.

The McLaughlin et al. (1990) methods differed in 2 ways from those in our study. First, the sex-specific differences in cementum annuli described by Coy and Garshelis (1992) were not known to McLaughlin et al. (1990). Second, the cementum analysis method they used had not been described in a standardized, illustrated text: the method was taught verbally by experienced technicians. Our study used the standardized cementum aging criteria developed and tested for the first premolar of Alaska brown bears (G. M. Matson et al. 1993. A laboratory manual for cementum age determination of Alaska brown bear first premolar teeth, unpublished. Matson's Laboratory, Milltown, Montana, USA). The findings of Coy and Garshelis (1992) were incorporated into these criteria and were expected to improve accuracy of cementum aging.

Matson's Laboratory (G. M. Matson and J. K. Matson. 1995. Progress Report 14, unpublished. Matson's Laboratory, Milltown, Montana, USA) reported the relative agreement of known-age and cementum-age estimates for 61 black bear teeth aged in their laboratory during 1982–90 and 1994–95. During 1982–90, 10 (37%) of 27 teeth were incorrectly aged. Six of the errors were ± 1 year, and 4 of the errors were >1 year ($\bar{x}$ = 5 yr). In 1994, all 4 teeth were aged accurately ($\bar{x}$ = 1 yr); in 1995, 7 (23%) of 30 teeth were aged incorrectly, and all 7 errors were ± 1 year ($\bar{x}$ = 5 yr). To date, 94% of known-age black bear teeth processed and analyzed at Matson's Laboratory either have been aged correctly (62%) or within 1 year of the known age (32%). We found that 97% of our black bear teeth aged by Matson's Laboratory either had been aged correctly (92%) or within 1 year of the known age (5%). These results were the same as those of McLaughlin et al. (1990), who aged 98% of 56 teeth within 1 year of the known age, and indicate our attempt to reduce errors by using detailed, standardized criteria in a written and illustrated format may have had little benefit. However, although extensive experience may minimize aging errors, a written and illustrated manual is still useful as a training and educational tool.

In our study, the percentage of incorrect cementum age estimates increased with increasing age in both male and female black bears. Error ranged from 3 to 26% in males and 4 to 18% in females. The cementum annuli formed beyond the age of 5 years in both males and females may appear to be "double." For males, 1 member of the pair is an accessory line; however, in females, the second line is an additional year of age, with the paired appearance caused by an intervening year in which ≥ 1 cub was reared. Because paired annuli have different origins in the 2 sexes, simply counting the most prominent annuli to estimate age is more likely to produce error in older males than in older females. Although the percent error was large in some age classes, the median error for all age–sex classes was 0 years, and the mean errors ranged from -0.20 to 0.37 years among all age–sex classes. There was no bias in the mean error for females ($\bar{x} = -0.03$ yr, SE = 0.03), but there was a small positive bias in the mean error for males ($\bar{x} = 0.09$ yr, SE = 0.02), and both sexes combined ($\bar{x} = 0.04$ yr, SE = 0.02).

The problem of biased estimates for males could be reduced by use of age categories rather than exact ages: categorical error ranged from 3 to 11%, and direct error ranged from 3 to 26%. Because male ages are more likely to be overestimated, especially in older age classes, categorical error is much lower than direct error. Similarly, categorical error was lower than direct error for females. Sauer et al. (1966) noted that annuli decrease in thickness with increasing age, which causes annuli of some older teeth to condense such that they are not individually discernable. Thus, cementum annuli become more difficult to interpret with increasing age. Our results indicated a similar difficulty, as Willey (1974) reported for Vermont black bears and McLaughlin et al. (1990) reported for Maine black bears: error rates were greatest in the older age categories. However, significant difficulty in estimation of age does not usually occur until Pennsylvania black bears are 8–10 years old (G. M. Matson, personal observation). Unfortunately, inadequate sample sizes did not allow us to analyze error rates of specific age classes of black bears ≥ 5 years old.

When the aging criteria from Coy and Garshelis (1992) were used, the percentage of females ≥ 4 years old (i.e., females likely to have reared cubs) that were underestimated before 1992 could have been much larger than those aged since 1992 because the closely spaced paired annuli were potentially incorrectly identified as repeated, complex annuli of a single year. Our results indicated that, before 1992, 13 of 18 incorrectly aged females were underestimated. Similarly, when applied to males ≥ 5 years old, male-specific annulus characteristics could have resulted in a higher percentage of overestimates before 1992 because increasingly prominent accessory lines found in older-aged males were potentially incorrectly counted as annuli. Although our results seemed to support revising the aging criteria as reported by Coy and Garshelis (1992), the chi-square test was not significant. However, we note that sample sizes were small, especially for ≥ 5-year-old males; thus, we likely had low statistical power to detect differences in error distributions.

An annulus is formed during winter in black bears (Sauer et al. 1966, Coy and Garshelis 1992) and polar bears (Stirling et al. 1977). This most recently formed annulus first becomes apparent in histological sections of teeth extracted from black bears in late spring. The annulus becomes clearly visible after deposition of lightly staining cellular cementum resumes during early spring and creates an outer, visually contrasting layer. Without the visual contrast of a peripheral cementum layer, the most recently formed annulus may not be visible in early spring (Craighead et al. 1970, Pearson 1975). Therefore, black bears captured during the months of March, April, and May may have deposited annuli that were not yet apparent to the tooth-section reader. Error would have occurred in cases where the spring date of extraction was not provided at the time of age analysis, because the reader would have seen no visible evidence in the tooth section that the assumed 15 January annual birthdate had passed. We evaluated aging errors in teeth collected from March to May and found no evidence of lower accuracy.

In contrast, teeth aged from black bears captured during September–November had more errors than expected. A potential source of aging error in teeth from black bears killed in the fall is prominent accessory lines formed during summer (Coy and Garshelis 1992). Further investigation is needed to determine if this time period, associated primarily with the hunting season, corresponds to factors (e.g., environ-

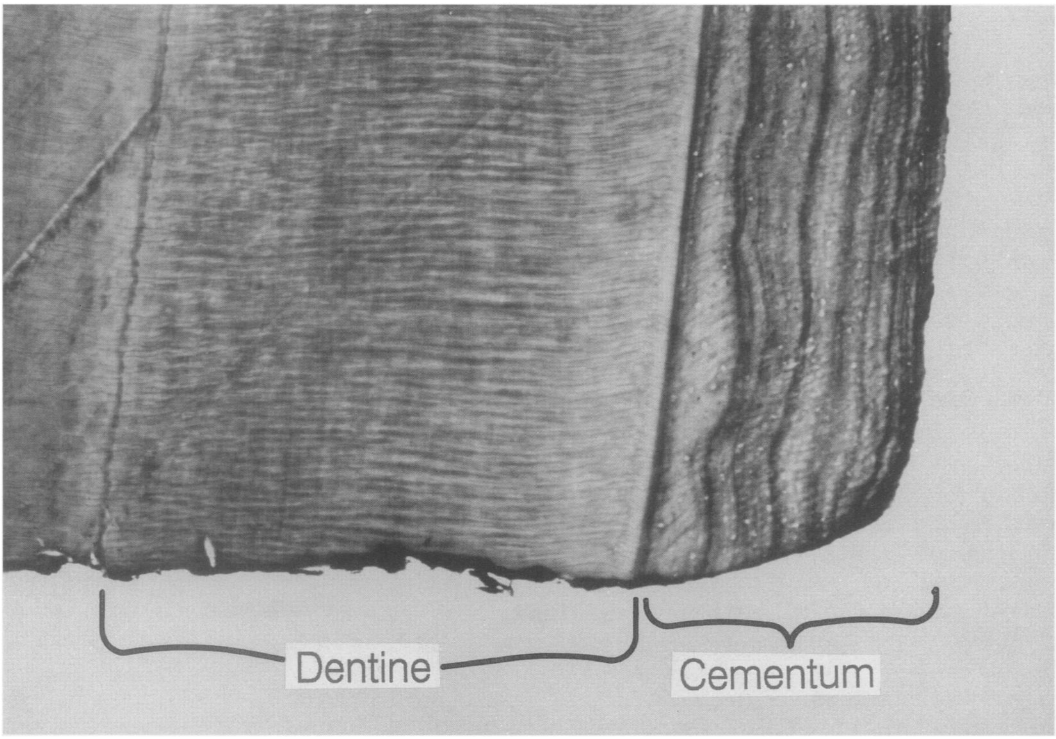

Fig. 1. This tooth was extracted from a 9-year-old, known-age female black bear who was aged incorrectly as 7 years old. Nine annuli might have been visible if the tooth had not been broken. In addition, the crown of the tooth was removed below the gum line, which may have created further difficulty in age estimation. Tooth breakage during extraction and poor tooth preparation are important sources of error when aging teeth.

mental or physiological changes) that affect cementum deposition. However, we note that many of the teeth used in our analysis were collected during the hunting season. Because hundreds of teeth are collected in a short period of time, handling errors may be greater and may partly explain the higher error rates.

Following our reevaluation of incorrectly aged teeth, we identified potential sources of aging errors. One source of error occurred when teeth were broken during extraction, and the resulting loss of cementum was believed to be a cause of underestimation error (Fig. 1). A second source of error involved irregular cementum characteristics to which standardized aging criteria could not be applied accurately (Fig. 2). Consequently, these first 2 sources of error were beyond the control of the tooth readers. Some environmental conditions, such as particularly abundant or scarce food resources, may cause the formation of irregular annuli, which could result in incorrect age estimates (Coy and Garshelis 1992). Also, some black bear populations have unusually prominent accessory lines that serve as important sources of error in younger black bears. Accessory lines are identified by their absence from some parts of the section where cementum annuli remain clearly and continually visible (G. M. Matson, personal observation). In younger black bears, however, they are not repeated often enough for the reader to recognize the paired annual pattern, which does not uniformly occur in all individuals. Another irregularly occurring cementum characteristic that potentially caused aging error was the presence of indistinct annuli. A third source of error was sex differences in cementum-annuli patterns that Matson's Laboratory aging criteria did not include until after they were described by Coy and Garshelis (1992; Fig. 3). Twelve of 13 teeth characterized with this type of error were aged during 1983–91, but these teeth probably would have been aged correctly with the revised aging criteria. A fourth source of error was presumed to be a result of tooth misidentification because the aging criteria for the sections were so well satisfied that the chance of error for these teeth

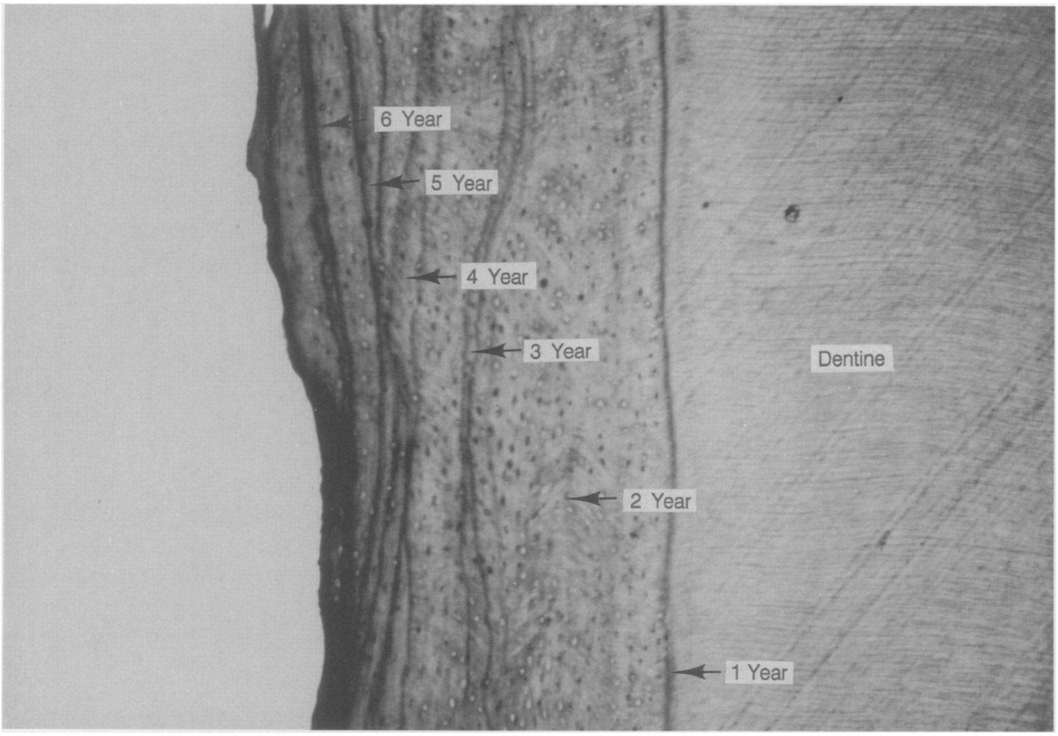

Fig. 2. This tooth was extracted from a male black bear with a known age of 6 years but was aged incorrectly as 5 years old. The indistinct 1-year annulus is atypical and exemplifies errors caused by unusual and unpredictable cementum variations.

was considered remote (Fig. 4). Misidentified teeth could be the result of physical switching of teeth by field or lab personnel or data-recording errors; however, we had no evidence that could confirm this type of error.

In addition to these sources of errors, tooth sections prepared at Matson's Laboratory prior to 1990 did not include the tooth's crown. As a result, valuable gum-line cementum was removed from an area of the tooth where annuli are most distinct (Fig. 1). Age estimation is most accurate when a complete tooth section is obtained, because a reader can better differentiate accessory lines from annuli. Therefore, although identification of this type of error in tooth sections is difficult, removal of crowns should be considered as a potential source of aging error.

Of the 51 incorrectly aged teeth that we reevaluated, 37 (73%) had aging errors attributed to specific characteristics of individual black bears, teeth being broken, or presumed misidentification of teeth. These sources cannot be controlled by readers and could potentially account for an overall error rate of 6% (37 of 671) of the teeth aged in this study. We determined that an error rate of 2% (13 of 671) could potentially have been caused by sex-specific cementum-annuli characteristics being incorrectly interpreted before 1992.

Accuracy of cementum aging is limited by physical and histological factors. The physical factors (e.g., broken or misidentified teeth) can be minimized by careful handling and sample preparation. However, histological characteristics of cementum will vary not only among different black bear populations, but also among individuals within the same populations. In Pennsylvania black bears, the spacing and prominence of the accessory line is an important potential error source, but is less so in other black bear populations. Precision and accuracy should be assessed for each black bear population to account for population-specific histological characteristics that produce error.

MANAGEMENT IMPLICATIONS

Age-specific estimates of population parameters (e.g., survival and birth rates) are lacking for many long-lived species of mammals (Jorgenson et al. 1997). One reason for this lack of data is because knowledge of the age of adults

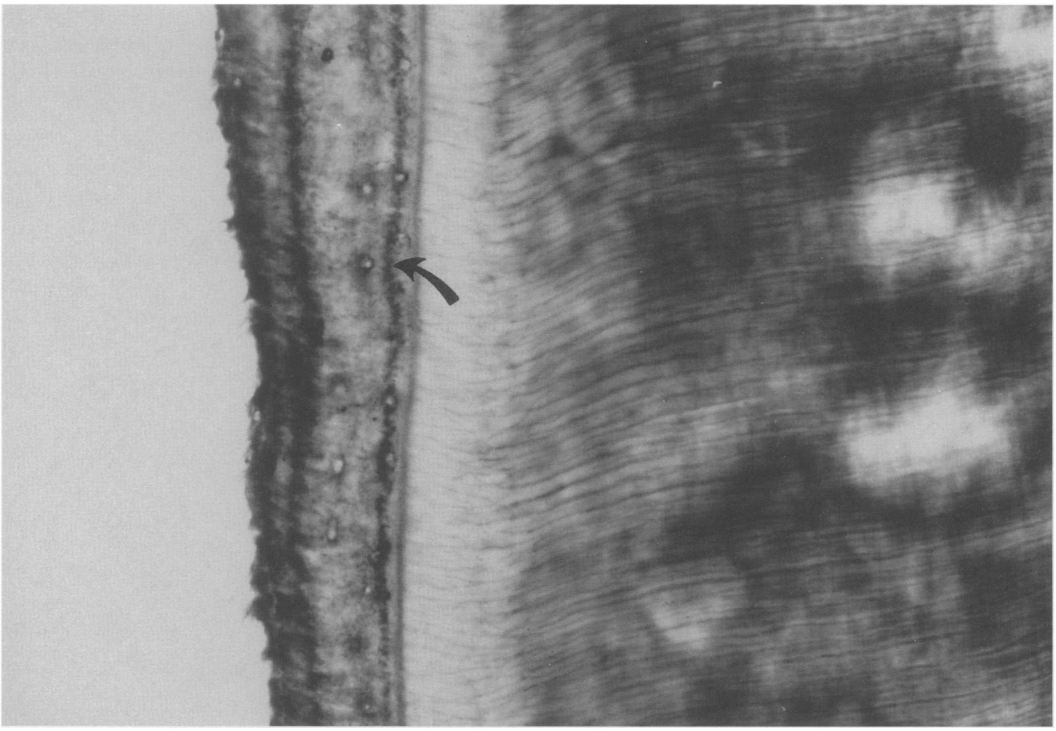

Fig. 3. This tooth was extracted in 1984 from a male black bear with a known age of 2 years and was incorrectly aged as 1 year old. The 1-year annulus is clearly separated from the dentine–cementum junction in the illustrated portion of the tooth. Nearer the tip, however, the annulus is indistinguishable from the junction. Aging criteria used since 1992 for aging black bears probably would have prevented this aging error.

is available only for individuals first captured at an age that can be assigned unambiguously (e.g., cubs). Consequently, large samples of individuals marked at a known age are needed so that adequate numbers of older, known-aged individuals remain alive for study (Nichols et al. 1997). However, if captured black bears can be assigned an age accurately as an adult, then smaller sample sizes would be required when modern capture–recapture models are used to estimate age-specific population parameters (Buckland 1980, Laake 1992, Lebreton et al. 1992).

Our results indicated little or no bias for estimates of age for various age and sex classes of black bears when we used counts of tooth cementum annuli. Our overall error of 8.1% could have been reduced to about 6% if the revised aging criteria implemented in 1992 had been available for teeth aged before that year, and if the 13 teeth aged incorrectly for unexplained reasons were physically mishandled (e.g., teeth or tooth slides were switched). However, human error while labeling and physically handling teeth is unavoidable, and some teeth have irregular cementum characteristics that cannot be aged correctly. Despite these sources of error, however, we believe that counting tooth cementum annuli is an accurate technique for aging Pennsylvania black bears because the percentage of teeth aged incorrectly was small, and the mean aging error indicated little or no bias.

To obtain the accurate age estimates, cementum aging error for any population of black bears can be minimized by the following: (1) avoid breaking teeth or damaging the cementum layer; (2) do not boil skulls or mandibles to facilitate extraction, because boiling lessens differential staining of annuli; (3) do not clean teeth with corrosive chemicals (e.g., bleach), because corrosive chemicals destroy cementum; (4) keep careful records of sex and date of tooth extraction and verify physical transfer of teeth; (5) require that tooth readers use a written and illustrated method for cementum aging that includes criteria for interpretation and identifies potential error sources; (6) for cementum aging, use readers who are experienced with a stan-

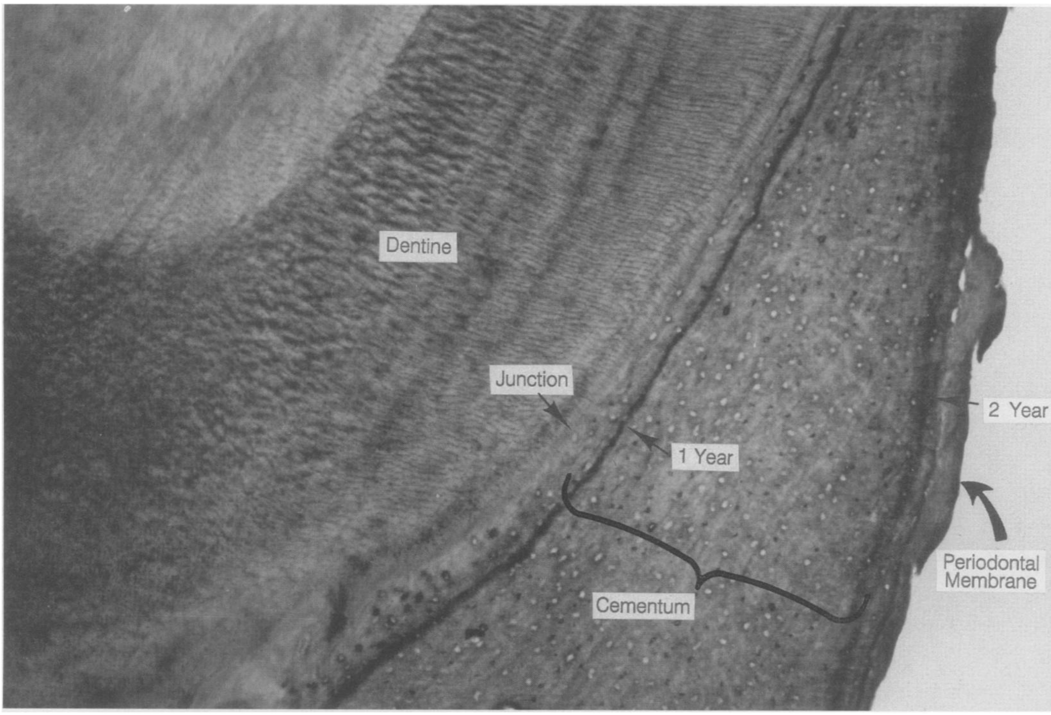

Fig. 4. This tooth was extracted from a female black bear with a known age of 4 years and was incorrectly aged as 2 years old. The 2 distinct annuli, and intact cementum layer as evidenced by the presence of the periodontal membrane, suggests this aging error is the result of tooth misidentification.

dardized aging method and who have been tested for accuracy and precision; (7) continually test tooth readers via teeth from known-age black bears or 2 teeth from the same black bear in which pair identification is withheld from the reader.

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