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A FIELD-BASED METHOD FOR ESTIMATING AGE IN FREE-RANGING STELLER SEA LIONS (*EUMETOPIAS JUBATUS*) LESS THAN TWENTY-FOUR MONTHS OF AGE

JAMES C. KING
THOMAS S. GELATT[1]
KENNETH W. PITCHER
Alaska Department of Fish and Game,
Division of Wildlife Conservation,
525 West 67th Avenue,
Anchorage, Alaska 99518, U.S.A.
E-mail: jamie_king@fishgame.state.ak.us

GREY W. PENDLETON
Alaska Department of Fish and Game,
Division of Wildlife Conservation,
P. O. Box 240020,
Douglas, Alaska 99824, U.S.A.

ABSTRACT

Studies of health, survival, and development of juvenile Alaskan Steller sea lions (*Eumetopias jubatus*, SSL) require accurate estimates of age for wild-captured animals. However, the value and accuracy of several potential predictors of age have not been assessed with data from known-age free-ranging animals. During 2001–2005, forty-six individual SSL originally branded or tagged at $\leq$6 mo of age were recaptured by the Alaska Department of Fish and Game (ADF&G). Using a series of general linear models, we evaluated the ability of morphometrics measurements: permanent canine tooth length (CTL), diastema (DIAS), whisker length (WHIS), and dorsal standard length (DSL) to predict the age of forty-six known-age juveniles ($n = 46 \leq 23$ mo of age). Permanent CTL was the strongest individual predictor ($r^2 = 0.80$); followed by DSL, DIAS, and WHIS ($r^2 = 0.70$, 0.56, and 0.45, respectively). The inclusion of a single sample from a 44-mo-old sea lion suggested quadratic relationships between age and all predictors for older animals. Only models including CTL predicted age to within 6 mo of known age. The equation Age $= (-3.0112 + [0.6726 * \text{CTL}] + [0.4965 * \text{DIAS}])$ allows for accurate age estimates of SSL $\leq$23 mo for both sexes.

Key words: age estimation, known-age, canine length, diastema, Steller sea lion, *Eumetopias jubatus*, Alaska.

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[1] Current address: National Marine Mammal Laboratory, Alaska Fisheries Science Center, 7600 Sand Point Way, Seattle, Washington 98115-6349, U.S.A.

Studies of health, survival, life history, and development of juvenile Alaskan Steller sea lions (*Eumetopias jubatus*, SSL) require accurate estimates of age for wild-captured animals. Particularly valuable would be a noninvasive technique that could be rapidly utilized at the time of capture to guide age-specific procedures such as telemetry instrumentation or tissue sampling. Pups <6 mo of age are readily identifiable in the field by their small body size and thick dark pelage. However, once pups have molted at approximately 5–6 mo of age, they cannot be aged by pelage and size alone. Sea lions between 6–12 mo and 18–24 mo can have similar pelage and overlapping size (Calkins and Pitcher 1982, Calkins *et al.* 1998, Daniel 2003), suggesting body size alone, or in combination with molt stage may be unreliable predictors of age in juveniles.

Other morphometrics may be useful predictors of age in pinnipeds. A large diastema (DIAS) (space between teeth in the jaw) between postcanine (pc) (teeth occurring posterior of the canine) 4 and pc 5 that has been observed in adult SSL is absent in pups but may increase with age (King 1983, Fig. 1). Results from studies of cementum and dentin analyses of canine teeth suggest correlations between growth of teeth and body size in pinnipeds (Boyd and Roberts 1993); cementum and dentin analyses of canines have commonly been used to determine the age of SSL (Fiscus 1961, Spalding 1964) and other large mammals. Major oscillations in ratios of stable isotopes in SSL whiskers may provide an annual foraging record (Hirons *et al.* 2001), suggesting SSL retain their whiskers and whisker growth may be useful in estimating age. Whisker length (WHIS) may provide an easy age index for stable isotope studies of foraging behavior for samples from live-captured, stranded, and collected animals for which other methods of estimating age are not available.

Because of difficulty capturing SSL >6 mo of age and the lack of large numbers of marked, known-age animals, assessing changes in morphometrics with age was not previously possible without the collection of animals and/or estimation of age using tooth cementum and dentin analyses, which requires the removal of a tooth (Fiscus 1961, Spalding 1964, Calkins and Pitcher 1982, Calkins and Goodwin 1988). Permanent marking of SSL pups <6 mo of age since 2000 for life history studies coupled with the development of a dive capture technique using SCUBA in the late 1990s (Raum-Suryan *et al.* 2004) allowed recapturing of branded juveniles and provided larger sample sizes of live known-age SSL. In this study, we assessed the accuracy of several predictors of age including dorsal standard length (DSL, Committee on Marine Mammals 1967, McLaren 1993.), whisker length (WHIS), permanent canine tooth length (CTL), DIAS between pc4 and pc5 (DIAS), and tooth eruption patterns for known-age free-ranging SSL captured between 2001 and 2005.

METHODS

Forty known-age individuals were provided by hot branding ($n = 39$) (Merrick *et al.* 1996) or tagging ($n = 1$) pups 3–6 wk of age at their natal rookies in the Aleutian Islands (AI), Gulf of Alaska (GOA), and Southeast Alaska (SEA) between 2000 and 2004 by the Alaska Department of Fish and Game (ADF&G) and the National Marine Mammal Laboratory (NOAA Fisheries). Six known-age individuals were also provided by branding pups 2–5 mo of age (when pups are still readily identifiable in the field) first captured during dedicated capture trips outside the breeding season. The natal rookery of these pups was uncertain because SSL pups can disperse with their mothers either late in the breeding season (mid May–July)

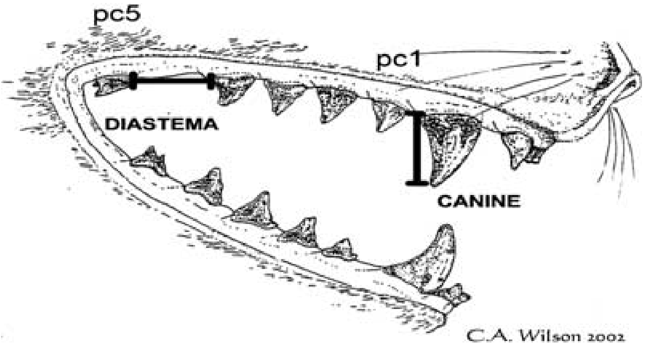

Figure 1. Tooth measurements (to the nearest 0.01 mm) of the upper right side of a Steller sea lion (SSL) mouth for age prediction variables.

or shortly thereafter (Raum-Suryan *et al.* 2002, ADF&G). Forty-six recaptures of the forty-five known-age individuals ($n_{\text{males}} = 30$; $n_{\text{females}} = 15$, one male was recaptured twice) provided samples to assess the feasibility of using various morphometrics to predict age of juveniles. We recaptured the forty SSL (one recaptured twice) of known natal rookery origin at 3–23 mo of age (natal rookery: $n_{\text{AI}} = 1$, $n_{\text{GOA}} = 18$, $n_{\text{SEA}} = 20$); and seven individuals 2–11 mo old (<6 mo $n = 6$, 11 mo $n = 1$) of unknown natal rookery origin. One of the SSL of unknown natal rookery was the oldest juvenile recaptured in this study, a 44-mo-old male. This individual was first captured and marked at 11 mo of age such that its age is less certain and its data were not included in the analyses. However, because this was the only recaptured SSL >2 yr of age, we do discuss how its measurements relate to the analyses based on younger animals. Juveniles were recaptured underwater using SCUBA ($n = 45$) or on land ($n = 2$) with a capture net and were fully immobilized with isoflurane gas (Heath *et al.* 1997) prior to collecting all measurements.

We measured CTL as the crown length of the upper right canine from the posterior base of the tooth at the gum line to the tip of the tooth (Fig. 1). We measured DIAS on the upper right side of the jaw, from the posterior base of pc4 to the anterior base of pc5 (Fig. 1). Teeth were measured using digital calipers to the nearest 0.01 mm, two to three times to ensure accuracy. We measured DSL as the straight-line distance from the tip of the nose to the tip of the tail with the animal lying on its ventrum using a standard measuring tape to the nearest 0.5 cm. We measured WHIS as the distance from the base of the longest whisker on the left side at the skin to the tip using a standard ruler to the nearest 0.1 cm. Measurements were taken repeatedly to ensure accuracy. Tooth eruption was recorded for each tooth in the upper right jaw. Degrees of eruption were categorized subjectively as *milk* (non-permanent or deciduous tooth), *not erupted* (no deciduous or permanent tooth present but permanent tooth could be felt in gum), *partially erupted* (permanent tooth had broken skin and was visible below gum line), *erupted* (permanent tooth fully exposed from gum, but more eruption is expected to occur), and *fully erupted* (tooth is not expected to erupt more, proportionally to the other teeth, but may still increase in size).

Statistical Analysis

We used a series of general linear models to predict age of juveniles (2–23 mo of age) based on the predictor variables CTL ($n = 28$ recaptures), DIAS ($n = 30$), DSL ($n = 46$), and WHIS ($n = 46$). Reduced sample sizes of teeth measurements resulted from the presence of milk (nonpermanent) teeth or teeth that were not erupted. In a few cases data were not available because field measurements had not been collected. We evaluated stock and sex in the models to see if prediction equations varied with these factors. Within Alaska two SSL stocks are recognized based on genetic evidence and demographics (Bickham *et al.* 1996): the endangered, severely reduced western stock (includes AI and GOA in this study) and the threatened but stable or increasing eastern stock (includes SEA in this study). Sex was included because growth patterns vary between male and female SSL. Body size is highly dimorphic for SSL with males being larger than females even at an early age (Winship *et al.* 2001, Brandon *et al.* 2005). Both sexes experience rapid growth in the early years of life, however males continue to grow beyond 5 yr of age and can exceed 3 m in length and weights over 1 ton (Calkins and Pitcher 1982, King 1983).

Because predictors were highly correlated, a backward or forward stepwise procedure was used in modeling predictors in which variables were deleted or added one at a time. Although these correlations may affect significance tests, we were most concerned with developing predictive equations, rather than tests for "significance." We also centered the predictors (*i.e.*, subtracted the mean value of the predictor from all observations prior to analyses), to reduce the correlation between the linear and quadratic terms.

We fitted two series of models. In the first series, for branded juveniles of known natal rookery $\leq$23 mo old ($n = 39$), we examined each predictor singly. We started with the linear and quadratic terms for the predictor, sex, stock, and all two- and three-way interactions. We fitted reduced models, eliminating terms one at a time based on Wald P-value. The final model was chosen when all remaining terms were important (all $P < 0.05$). We then fitted a second series of models for all data including those of unknown natal rookery (SSL $\leq$23 mo, $n = 46$) that used the continuous predictors only. We started with each predictor as a single linear term, added its quadratic form, and then fitted models with combinations of the predictors, with both linear and quadratic terms. For all models in all series, we calculated r^2 and the maximum residuals (both positive and negative); the residuals are the differences between the actual ages of SSL in the data set and the ages predicted by each model. Although our models examined age by month as a continuous variable, SSL are pulse breeders giving birth only from May to July each year (Pitcher *et al.* 2001). Consequently, only year-class must be correctly identified to accurately estimate age. The maximum residuals are the greatest underestimate and overestimate of age for a particular model. A criterion that was particularly useful in comparing models and judging accuracy of predictors was to accept maximum and minimum errors in age (residuals) of no greater than 6 mo, thus ensuring year class would be estimated correctly.

RESULTS

In the first series, only the CTL model met the criteria of both maximum under- and overestimates of predicted ages of <6 mo (Table 1). Stock was important only for DSL (Table 1, Fig. 2c). For an animal of a given length, those from the western stock were 2.5 mo younger than eastern stock juveniles. Sex was important only for WHIS

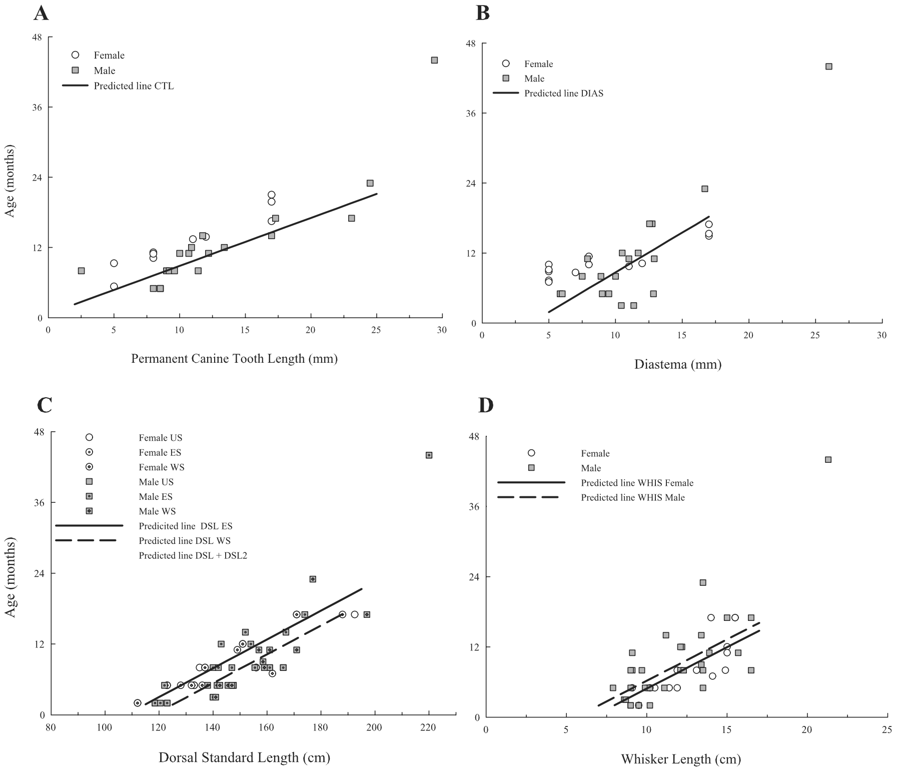

Figure 2. Predictive variables of age for free-ranging Steller sea lions (SSL) in Alaska. CTL = permanent canine tooth length, DIAS = diastema, DSL = dorsal standard length, WHIS = whisker length. Regression lines from models in Table 1. (A) CTL Series 2. Model 5. (B) DIAS Series 1. Model 2. (C) DSL ES and WS Series 1. Model 3. (D) WHIS Female and Male Series 1 Model 4. US = unknown stock, ES = eastern stock, WS = western stock.

(Table 1, Fig. 2d). Females were 1.3 mo younger for a given WHIS than males. Based on r^2 and maximum residuals, CTL was the strongest individual predictor ($r^2 = 0.80$, prediction error <5.3 mo, Table 1, Fig. 2a). DSL was similar in predictive power when stock was also included ($r^2 = 0.78$, Table 1, Fig. 2c), however, the predication error exceeded 6 mo. DIAS and WHIS lengths were poorer single predictors ($r^2 =$ 0.56 and 0.47, respectively, Table 1).

In the second model series, which did not include sex or stock as factors, models based on CTL had the highest r^2 (0.80–0.91) and only models containing CTL had all prediction errors of <6 mo (Table 1). The best model with the fewest variables included CTL and DIAS ($r^2 = 0.91$; all prediction errors <2.6 mo). Performance of this model changed little with the addition of DSL or WHIS ($r^2 = 0.91$; all prediction errors ≤ 2.7 mo, Table 1). Models based on WHIS were particularly weak ($r^2 = 0.45$) and did not significantly improve performance of other predictors when included (Table 1). We suggest that a useful and accurate equation for estimating ages of SSL to ≤ 23 mo is given by $\text{Age} = -3.0112 + (0.6726 * \text{CTL}) + (0.4965 * \text{DIAS})$. The equation including DSL with CTL and DIAS was more accurate and

Table 1. Performance of age prediction models for juvenile Alaskan Steller sea lions (SSL) by predictor variable, sex, and stock.

Model	r^2	Largest underestimate (mo)	Largest overestimate (mo)
Model series 1: ≤ 23 mo			
1. CTL	0.800	5.3	3.3
2. DIAS	0.564	5.2	7.5
3. DSL + stock	0.778	8.6	3.8
4. WHIS + sex	0.467	11.8	7.4
Model series 2: ≤ 23 mo			
5. CTL	0.800	5.3	3.3
6. CTL + CTL^2	0.810	4.0	3.3
7. DIAS	0.564	5.2	7.5
8. DIAS + DIAS^2	0.611	5.7	6.8
9. DSL	0.704	8.5	4.3
10. DSL + DSL^2	0.707	8.4	4.1
11. WHIS	0.452	12.4	6.6
12. WHIS + WHIS^2	0.452	12.3	6.5
13. CTL + DIAS	0.906	2.5	2.6
14. CTL + DSL	0.852	4.0	2.3
15. CTL + WHIS	0.802	5.2	3.2
16. DIAS + DSL	0.731	6.2	4.7
17. DIAS + WHIS	0.727	6.2	4.7
18. DSL + WHIS	0.715	8.8	4.6
19. CTL + DIAS + DSL	0.910	2.5	2.3
20. CTL + DIAS + WHIS	0.907	2.4	2.7
21. DIAS + DSL + WHIS	0.767	6.4	3.9

CTL = permanent canine tooth length in mm; DIAS = diastema between postcanine (pc) 4 and pc5 in mm; DSL = standard body length in cm; WHIS = whisker length in cm. Sex and stock (eastern and western).

may also be useful to estimate age, having a slightly higher r^2 and smaller prediction errors: Age $= -6.4102 + (0.6313 * \text{CTL}) + (0.4026 * \text{DIAS}) + (0.0313 * \text{DSL})$ (Table 2.).

Several general tooth eruption sequences observed appeared age related. At 3 mo of age, all permanent pc had erupted through the gum and milk or nonpermanent incisors had fallen out, and in most cases the permanent incisor had erupted. Permanent canines were evident in most animals at 4–5 mo. At 9–11 mo, the canines began to extend equal to or past the incisor and by 15 mo were erupted proportional to the rest of the teeth, although more eruption and growth was expected to occur.

DISCUSSION

Field estimations of SSL age for juveniles >6 mo of age have often relied on subjective evaluation by experienced personnel of morphometric characteristics such as mass, length, and teeth eruption patterns. Postcanine teeth have been extracted from live-captured SSL juveniles in the wild in order to estimate ages by counting

Table 2. Age estimation formulas based on regression coefficients for selected age prediction models for Steller sea lions (SSL) <24 mo of age.

Series # model #	Model	Formula
Series 1. 2	DIAS	$\text{Age} = -4.9579 + (1.3633 * \text{DIAS})$
Series 1. 3	DSL + Stock (ES)	$\text{Age (ES)} = -26.2686 + (0.2440 * \text{DSL})$
Series 1. 3	DSL + Stock (WS)	$\text{Age (WS)} = -28.7953 + (0.2440 * \text{DSL})$
Series 2. 5	CTL	$\text{Age} = 0.6512 + (0.8200 * \text{CTL})$
Series 2. 6	$\text{CTL} + \text{CTL}^2$	$\text{Age} = 3.0733 + (0.4227 * \text{CTL}) + (0.0140 * \text{CTL}^2)$
Series 2. 13	CTL + DIAS	$\text{Age} = -3.0112 + (0.6726 * \text{CTL}) + (0.4965 * \text{DIAS})$
Series 2. 14	CTL + DSL	$\text{Age} = -9.4174 + (0.6292 * \text{CTL}) + (0.0793 * \text{DSL})$
Series 2. 19	CTL + DIAS + DSL	$\text{Age} = -6.4102 + (0.6313 * \text{CTL}) + (0.4026 * \text{DIAS}) + (0.0313 * \text{DSL})$

CTL = canine length (mm), DIAS = diastema length (mm), DSL = dorsal standard length (cm), WHIS = whisker length (cm).

cementum and dentin layers. Although previously few data from known-age SSL have been available to validate age estimates from tooth growth layer groups (GLG) (Calkins and Pitcher 1982, $n = 9$ individuals branded as pups and later collected as adults), the technique has been thought to be accurate within ±1 yr when canine tooth was used (Fiscus 1961). However, aging young SSL can be difficult due to a lack of cementum layer and obscure growth lines in the dentin, greater accuracy was obtained with younger animals in early studies of growth in SSL (Fiscus 1961). Ageing SSL with teeth growth lines cannot be accomplished during the course of field handling of the animal. Furthermore, whether or not removing a tooth from live free-ranging pinniped compromises foraging efficiency or health is unknown (Childerhouse *et al.* 2004). This study presents a noninvasive alternative to tooth extraction that is potentially more accurate than cementum, dentin, or GLG analysis (maximum errors of <2.6 mo for some models), for free-ranging SSL <24 mo of age.

Our results demonstrate the utility of CTL and DIAS measurements, in conjunction with standard body size measurements (length and mass), for immobilized live-captured SSL in the field. Models containing CTL and DIAS can provide very accurate estimates of year class (maximum errors <2.6 mo) for pups and 1- and 2-yr-olds, independent of stock or sex. This suggests teeth growth patterns in SSL are more conservative than body growth patterns as there is overlap in mass between age classes. Although DSL is useful in estimating age when stock is known, age estimates are less reliable than those also considering tooth measurements as well. The need to know stock can also limit accuracy of age estimation when using DSL for juveniles. Juvenile SSL have been observed traveling distances of 1,785 km from their natal rookery, crossing stock boundaries, and are capable of traveling >400 km from natal rookeries by 5 mo of age (Raum-Suryan *et al.* 2002). Thus, locality of captures cannot predict rookery or even stock origin with absolute certainty and restricts the effectiveness of using stock as a predictor. Teeth measurements are particularly useful in captures outside the breeding season, when natal rookery is uncertain. Although presence of milk teeth or nonerupted teeth may limit the utility of the

CTL measurement for some animals (37% of recaptures, without permanent canines in our study), all of these animals were <8 mo of age so aging by pelage type, body size, and teeth eruption patterns was reliable. Of these recaptures 82% were <5 mo of age and all had milk canines; 18% were 7–8 mo (one individual had a milk canine and its incisor was not erupted; two individuals had no canine tooth (milk or permanent). The pc needed for DIAS are erupted at birth or soon thereafter (<3 mo). However it should be noted that the eruption sequence of pc on the upper jaws in SSL varies in that pc1, 3, and 5 are erupted at birth but pc2 and pc4 are erupted later (Spalding 1966, this study). Special care should be taken while measuring DIAS due to the eruption sequence of the pc and the difficulty of this measurement.

Variation between sexes in growth patterns of SSL $\leq$ 23 mo was observed only with female whiskers being longer than male whiskers; however, sample sizes of females in our study were small ($n = 15$). Other studies have reported larger size and more rapid growth in male *versus* female SSL (Winship *et al.* 2001, Brandon *et al.* 2005). Although in the 1990s body size of pups <6 wk of age from the AI and GOF (western stock) have been observed to be larger than those from SEA (eastern stock) (Brandon *et al.* 2005), similar stock differences in body size of juvenile SSL has not been previously reported (this study, Fadely *et al.* 2005).

We performed similar analysis to those in model series 2 (Table 1) but including data from the one 44-mo-old male. These analyses suggest what might occur to our equations with older juveniles. For all predictor variables, these models suggest nonlinear relationships with age (*e.g.*, quadratic models) as growth slows from the linear pattern of SSL <24 mo old. Of most importance is the growth in CTL that, as expected, seemingly has slowed and could stop at some point in the animals life, although this has not been documented with sufficient samples of known-age SSL (Fiscus 1961). This also highlights that caution is required if using our equations for animals >24 mo of age, as prediction errors could be larger for older animals than those of SSL <24 mo. Canine wear has been observed in older animals necropsied by ADF&G, but the lack of recaptures of known-age older animals (>23 mo) has hampered our ability to assess the rate at which wear occurs or how it may vary among animals and/or sex. It is also unknown if the tooth root continues to grow throughout the life of SSL as it does with other pinnipeds (Scheffer 1950). In addition to the one 44-mo-old SSL included here, we also examined four canines from skulls of older SSL (one known-age 13-yr-old) from the ADF&G collection and pulp cavities in all canines had filled, suggesting that root growth at least slows later in life. The focus for this study was on SSL <24 mo of age because the majority of SSL captured and the focus for much of the other research being conducted on free-ranging wild-captured SSL is on younger animals. Data from older juveniles are needed to develop predictive equations for juveniles >23 mo, and as we advance toward capture methods allowing us to handle older, larger animals, we will need to increase the sample size of older animals to extend these equations.

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