CHAPTER 6

Suture age as an indicator of physiological age in the male Cape fur seal, *Arctocephalus pusillus pusillus* (Pinnipedia: Otariidae)

C. L. Stewardson, T. Prvan and M. A. Meÿer and S. Swanson

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ABSTRACT

In this study we examine suture age as an indicator of physiological age in the male Cape fur seal, *Arctocephalus pusillus pusillus*, from the coast of southern Africa. We describe the sequence of cranial suture closure (n = 11 sutures), determine whether suture age corresponds to chronological age, and estimate asymptotic size from suture age using nonlinear growth models (logistic, von Bertalanffy, Gompertz) fitted to cross-sectional morphometric data (n = 10 variables). Animals (n = 68 males) ranged in age from < 1 mo to ≥ 12 y (80 to 201 cm). Nineteen animals were of known-age (animals tagged as pups), 45 were aged from incremental lines observed in the dentine of upper canines and 4 were not aged. The sequence of partial suture closure differed from the sequence of full suture closure, with fusion beginning at different ages and some sutures taking longer to close than others. In animals ≤ 12 y, the sequence of full suture closure was the basioccipito-basisphenoid, occipito-parietal, interparietal/coronal and finally the squamosal-jugal. Suture age was found to be an unreliable indicator of chronological age. However, the basioccipito-basisphenoid can be used independently as an indicator of age, i.e., suture open = male ≤ 3 y old; suture fully closed = male 3–4 y or older and male has reached puberty. Asymptotic size estimates for 10 morphological measurements inferred from suture age are documented, and where possible, compared to asymptotes derived from chronological age.

Key words: Pinnipeds, Otariidae, suture age, asymptotic size

INTRODUCTION

Age determination in pinnipeds is important in many biological studies, particularly those examining development and growth. Various techniques have been used to determine absolute and relative age in pinnipeds. Techniques include: examination of tooth structure, the use of incremental structures in nails and bones, suture closure, standard body length, baculum development, eye lens weight, ovarian structure, and pelage characteristics (see Laws, 1962; Jonsgard, 1969; Morris, 1972; McCann, 1993 for reviews). Currently, examination of tooth structure is the most precise method of age determination in pinnipeds (Scheffer, 1950; Laws, 1953; McCann, 1993). In the majority of species however, the pulp cavity closes at some stage which terminates tooth growth (McCann, 1993).

In *Arctocephalus pusillus pusillus*, Cape fur seal, it is not possible to determine chronological age of animals > 13 y from examination of tooth structure because of pulp cavity closure. Examination of growth and development of the skeleton (physiological age) is thought to be one of the more useful methods of estimating relative age in older specimens (e.g., Rand, 1949, 1956). It has been suggested that in marine mammals, physical development may be better correlated with parameters which indicate the individual's proximity to physical maturity than with fixed morphometric values such as chronological age (Hui, 1979). In pinnipeds, cross-sectional data is typically used for growth studies. If growth patterns have been unchanged over the lifetime of the oldest animal, then the fitted growth curve will estimate the average of the growth curves of individual animals. This assumption is known as stationarity. However, many pinnipeds have been subject to periodic harvest and compete with a growing fishing industry. When the effects of anthropogenic activity on pinniped populations are taken into consideration, it is probable that 'individual' growth rates and patterns are indistinct when values are averaged using this method. Change in growth will take place at a slower or faster rate than is the case for an 'individual' (Sinclair, 1973; Hui, 1979).

Here we use suture closure (suture age) as an indicator of physiological age in the male Cape fur seal. Specific objectives were to: (i) describe the sequence of cranial suture closure, (ii) determine whether suture age corresponds to chronological age, and (iii) estimate asymptotic size inferred from suture age using nonlinear growth models fitted to cross-sectional morphometric data.

MATERIALS AND METHODS

Collection of specimens and morphometry

Male Cape fur seals were collected along the Eastern Cape coast of South Africa between Plettenberg Bay (34° 03'S, 23° 24'E) and East London (33° 03'S, 27° 54'E), from August 1978 to December 1995, and accessioned at the Port Elizabeth Museum (PEM). Collection procedures followed Stewardson *et al.*, 200X*a*, *b*, *c*. From this collection, 49 males were selected for examination, i.e., external body (*n* = 45 males), skull (*n* = 42 males) and bacular (*n* = 35 males) measurements.

The sample was supplemented with external body and skull measurements from 19 known-age animals (animals tagged as pups) from Marine and Coastal Management (MCM), Cape Town.

Animals (*n* = 68 males) ranged in age from < 1 mo to ≥ 12 y[1], with standard body lengths ranging from 80 to 201 cm. Nineteen animals were of known-age, 45 were aged from incremental lines observed in the dentine of upper canines (Stewardson *et al.*, 200X*a*), and 4 were not aged.

The following measurements were examined: external body (standard body length, tip of snout to genital opening, tip of snout to anterior insertion of front flipper, length of front flipper, length of hind flipper), skull (condylobasal length, bizygomatic breadth, mastoid breadth, length of mandible) and baculum (bacular length). Measurements were recorded according to Stewardson *et al.*, (200X*a*, *b*, *c*).

Sequence of suture closure

Eleven cranial sutures (Table 6.2) from 21 known-age skulls, and 45 canine aged skulls, were examined and assigned a value of 1–4, according to the degree of closure (1 = suture fully open; 2 = suture less than half-closed; 3 = suture more than half-closed; and 4 = suture completely closed) following Stewardson *et al.*, (200X*b*). These values were added to give a total suture index (SI), ranging from 11 (all sutures open) to 44 (all sutures closed).

Asymptotic size

Asymptotic size, inferred from suture age, was estimated by fitting three nonlinear growth curves (Table 6.1) to cross-sectional morphometric data (Table 6.5). Constrained nonlinear optimisation, using the Sequential Quadratic Programming algorithm, was used to estimate the parameters in each growth model. The residual sum of squares was used as the loss function. The nonlinear growth curves were fitted using SPSS (SPSS Inc., Chicago, Illinois, 1989-1999, 9.0.1).

RESULTS

Suture closure and chronological age

The relationship between suture age and chronological age (Fig. 6.1, Table 6.2, 6.4) was examined using known-age animals, 10 mo to 12 y (*n* = 21 males).

[1] In Cape fur seals, animals > 13 y can not be aged from counts of growth layer groups in the dentine of upper canines because the pulp cavity closes which terminates tooth growth, hence the age group '≥12 y'. Estimated longevity is *c.* 20 y.

Table 6.1 *Growth models fitted to cross-sectional morphometric data for male Cape fur seals*

Model	Equation	References
Logistic	$y = \dfrac{a}{1 + b\exp(-cx)}$	Batschelet (1975); Innes *et al.*, (1981)
Gompertz	$y = a\exp(-b\exp(-cx))$	Laird (1966); Innes *et al.*, (1981)
von Bertalanffy	$y = a(1 - b\exp(-cx))^3$	Turner *et al.*, (1976); Innes *et al.*, (1981)

a, asymptote (line tangent to the curve at infinity).
b & c, fitted constants.
$\exp(x) = e^x$, where e is the base of the natural logarithms.

The sequence of partial suture closure (PSC) differed from the sequence of full suture closure (FSC) with fusion beginning at different ages and some sutures taking longer to close than others.

For the range of available specimens, the sequence of PSC according to chronological age was coronal (PSC at 2 y), occipito-parietal (PSC at 3 y), interparietal (PSC at 4 y), squamosal-jugal (PSC at 7 y) and premaxillary-maxillary (PSC at 12 y). Considering that the basioccipito-basisphenoid was fully closed at 3–4 y, PSC would occur at 1 or 2 y, before or at the same time as the coronal. The squamosal-parietal, interfrontal, basisphenoid-presphenoid (sutures of the brain case), internasal and maxillary (sutures of the face), showed no signs of partial closure in animals ≤ 12 y.

The sequence of FSC according to chronological age was basioccipito-basisphenoid, occipito-parietal, interparietal/coronal and finally squamosal-jugal. With the exception of the squamosal-jugal these are sutures of the brain case. The basioccipito-basisphenoid was fully closed at 3–4 y. The occipito-parietal was fully closed in some animals as early as 5 y. The interparietal was fully closed in one 9-y-old and one 12-y-old. The coronal was fully closed in one 9-y-old and one 12-y-old. The squamosal-jugal was fully closed in one 12-y-old.

Although the sutures and their pattern of closure were clearly related to each other, the relationship

Table 6.2 *Suture index for male Cape fur seals according to chronological age (y) and age group (known-age animals tagged as pups)*

No.[a]	Suture[b]	Yearling	Subadults						Adults	
		10 mo	2 y	3 y	4 y	5 y	6 y	7 y	9 y	12 y
vii.	**Basioccipito-basisphenoid** (brain case)	1	1	**4**	**1[d]–4**	**4**	**4**	**4**	**4**	**4**
i.	**Occipito-parietal** (brain case)	1	1	3	2–3	**4**	**3–4**	**3**	**4**	**4**
ii.	**Interparietal** (brain case)	1	1	1	1–2	1–2	1–3	2	**4**	**4**
iii.	**Coronal** (brain case)	1	1–2	2	2–3	2	2–3	2	**4**	**4**
x.	**Squamosal-jugal** (face-zygomatic)	1	1	1	1	1	1	1–2	1	**4**
vi.	**Premaxillary-maxillary** (face-maxilla)	1	1	1	1	1	1	1	1	2
xi.	**Maxillary** (face-maxilla)	1	1	1	1	1	1	1	1	1
ix.	**Squamosal-parietal** (brain case)	1	1	1	1	1	1	1	1	1
iv.	**Interfrontal** (brain case)	1	1	1	1	1	1	1	1	1
viii.	**Basisphenoid-presphenoid** (brain case)	1	1	1	1	1	1	1	1	1
v.	**Internasal** (face-nasal)	1	1	1	1	1	1	1	1	1
	Suture index[c]	11	11–12	17	13–19	18–19	18–21	18–19	23	27
	Total no. skulls = 21	**2**	**2**	**2**	**6**	**2**	**3**	**2**	**1**	**1**

[a] Suture numbers i–xi correspond to Fig.2 in Stewardson *et al.*, (200X*b*).
[b] Sutures arranged in order of closure (1, suture fully open; 2, suture less than half-closed; 3, suture more than half-closed; 4, suture completely closed).
[c] Total value of the 11 cranial sutures (minimum and maximum). Note that the suture index is not necessarily the total value of each column.
[d] The basioccipito-basisphenoid was fully open in one 4-y-old (AP4496).

Table 6.3 *Suture index for male Cape fur seals according to standard body length*

		Standard body length (cm)												
No.[a]	**Suture**[b]	**80–90**	**91–100**	**101–110**	**111–120**	**121–130**	**131–140**	**141–150**	**151–160**	**161–170**	**171–180**	**181–190**	**191–200**	**201**
vii.	**Basioccipito-basisphenoid** (brain case)	1	**1–4**	**2–4**	**1–4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
i.	**Occipito-parietal** (brain case)	1	1	1–2	2–3	3	**4**	**3–4**	**3–4**	**3–4**	**4**	**4**	**4**	**4**
ii.	**Interparietal** (brain case)	1	1	1	1	1	1–2	**1–4**	**1–3**	**1–4**	**1–4**	**2–4**	**1–4**	**4**
iii.	**Coronal** (brain case)	1	1–2	1–2	2	2	1–2	1–3	2–3	**1–4**	**3–4**	**2–4**	**2–4**	**2**
x.	**Squamosal-jugal** (face-zygomatic)	1	1	1	1–2	1	1	1–2	1	1	**1–4**	**1–4**	**1–4**	**1**
xi.	**Maxillary** (face-maxilla)	1	1	1	1	1	1	1	1	1	1	1–3	**1–4**	**1**
vi.	**Premaxillary-maxillary** (face-maxilla)	1	1	1	1	1	1	1	1	1	1–2	1–3	1–3	1
ix.	**Squamosal-parietal** (brain case)	1	1	1	1	1	1	1	1	1	1–2	1–3	1–3	1
iv.	**Interfrontal** (brain case)	1	1	1	1	1	1	1	1	1	1–2	1–2	1–3	1
viii.	**Basisphenoid-presphenoid** (brain case)	1	1	1	1	1	1	1	1	1	1	1	1–2	1
v.	**Internasal** (face-nasal)	1	1	1	1	1	1	1	1	1	1	1	1–2	1
	Suture index[c]	11	12–14	13–16	13–17	17	17–19	17–21	18–21	17–23	19–27	20–33	18–33	21
	Total no. skulls = 65	**3**	**3**	**4**	**3**	**3**	**2**	**10**	**7**	**8**	**6**	**6**	**9**	**1**

[a] Suture numbers i–xi correspond to Fig.2 in Stewardson *et al.*, (200X*b*).
[b] Sutures arranged in order of closure (1, suture fully open; 2, suture less than half-closed; 3, suture more than half-closed; 4, suture completely closed).
[c] Total value of the 11 cranial sutures (minimum and maximum). Note that the suture index is not necessarily the total value of each column.

Table 6.4 ***Total suture score for ages 10 mo to 12 y showing age range in months, mean age ± S.E. and C.V. (known-age animals tagged as pups)***

Suture score	***n***	**Age range (mo)**	**Mean age ± S.E. (mo)**	**C.V.**
11	3	10–22	14.0 ± 4.0	49.5
12	1	20	20.0	–
13	1	46	46.0	–
16	1	46	46.0	–
17	4	34–47	41.5 ± 3.1	14.8
18	4	53–80	66.8 ± 5.5	16.6
19	4	53–80	66.3 ± 6.2	18.7
21	1	74	74.0	–
23	1	106	106.0	–
27	1	143	143.0	–
	21			

Where sample size is one, we cannot calculate S.E. of the mean or C.V.

was not sufficiently close to be used as a reliable technique for estimating chronological age (Table 6.4). The standardised residuals versus fitted values plots exhibited curvature; therefore, the straight line does not adequately describe the relationship between suture age and chronological age.

Suture closure and standard body length

The relationship between suture age and SBL (Table 6.3) was examined using animals 80–201 cm, 10 m to ≥ 12 y. SBL was not recorded for 3 animals (n = 65 males).

For the range of available specimens, the sequence of PSC according to SBL was basioccipito-basisphenoid, occipito-parietal/coronal, squamosal-jugal, interparietal, premaxillary-maxillary/squamosal-parietal/interfrontal, maxillary and finally the basisphenoid-presphenoid/internasal.

The sequence of FSC was basioccipito-basisphenoid, occipito-parietal, interparietal, coronal, squamosal-jugal and finally the maxillary. The basioccipito-basisphenoid was fully closed in all animals ≥ 118 cm, with FSC evident in some animals ≥ 96 cm. The occipito-parietal was fully closed in all animals ≥ 168 cm, with FSC evident in some animals ≥ 134 cm. The interparietal, coronal, squamosal-jugal and the maxillary were closed in some animals at 141, 170, 173 and 192 cm, respectively. The premaxillary-maxillary, squamosal-parietal, interfrontal, basisphenoid-presphenoid and internasal did not fully close in animals ≤ 201 cm.

Asymptotic size

Estimated asymptotic size was calculated using animals 80–201 cm, 10 m to ≥ 12 y (n = 65 males).

Parameters for the three growth functions are given in Table 6.5. Inspection of the residuals versus fitted values plots indicated that the three models were adequate for the range of values available. In terms of the R^2 (a goodness of fit statistic), the models were found to be quite similar. These models adequately described the ‘general’ growth pattern of the 10 variables for suture ages 11–33 (Fig. 6.2–6.11). The von Bertalanffy model for bacular length was the only exception. Asymptotic size derived from the latter was not considered to be reliable.

The logistic model gave consistently smaller asymptotic estimates than the other two growth models, and generally fell within the range of mean value for adults, and the maximum value for adults, reported in this study. Estimated asymptotic size was slightly larger than the maximum adult value for tip of snout to anterior insertion of front flipper, bizygomatic breadth and mastoid breadth (Table 6.5).

The von Bertalanffy model gave a slightly larger estimate than the Gompertz model. Asymptotic size estimates were similar for 8 of the 10 variables. Exceptions were standard body length (11 cm difference) and tip of snout to insertion of front flipper (9 cm difference). Estimates were similar to or slightly larger than the maximum value for adults reported in this study.

Asymptotic estimates derived from suture age were compared with those derived from chronological age to see if asymptotes were similar. The chronological age data did not have animals > 12 y (unable to canine age animals > 13 y), where as the suture age data contained animals > 12 y. Growth continued in most variables beyond 12 y. Therefore, there was insufficient information about the upper limits of the curves to estimate asymptotic size (y), preventing comparison with asymptotes derived from suture age. Bacular length and mandibular length were the only exceptions.

Growth in bacular length slowed in animals at *c.* 10 y, forcing the curve to plateau, providing sufficient information about the upper limits of the curve. Asymptotic size for bacular length derived from measurements based on suture age (logistic 119.1 mm; Gompertz 120.2 mm) was found to be very similar to asymptotic size derived from measurements based on chronological age (logistic 119.9 mm; Gompertz 124.2 mm) (Table 6.5).

Growth in mandibular length also slowed in animals at *c.* 10 y. Asymptotic size for mandibular length derived from measurements based on suture age (logistic 192.1 mm; Gompertz 196.0 mm; Von Bertalanffy 198.0 mm) was found to be very similar to asymptotic size derived from measurements based on chronological age (logistic 190.1 mm; Gompertz 196.1 mm; Von Bertalanffy 198.9 mm) (Table 6.5).

Table 6.5 *Growth parameters (mean ± asymptotic S.E.) of three growth models fitted to cross-sectional morphometric data for male Cape fur seals inferred from suture age*

Growth model	Parameters of growth curves					Adults only[a]	
	a	b	c	R^2	*n*	Mean value	Max. value
External body (cm)							
Standard body length					63	199 ± 3.6	201
Logistic	199.79 ± 6.39	16.13 ± 5.66	0.21 ± 0.03	82%		(*n* = 17)	
Gompertz	204.54 ± 8.05	5.63 ± 1.61	0.16 ± 0.02	81%			
Von Bertalanffy	215.18 ± 11.75	1.00 ± 0.25	0.12 ± 0.02	80%			
Tip of snout to genital opening					45	171.1 ± 3.4	184.0
Logistic	181.41 ± 12.31	11.34 ± 3.36	0.18 ± 0.03	85%		(*n* = 7)	
Gompertz	190.68 ± 17.08	3.99 ± 0.99	0.12 ± 0.03	84%			
Von Bertalanffy	195.46 ± 19.90	0.95 ± 0.23	0.11 ± 0.02	84%			
Tip of snout to anterior insertion of front flipper					45	94.2 ± 3.1	110.0
Logistic	115.15 ± 13.36	12.61 ± 4.61	0.16 ± 0.03	76%		(*n* = 7)	
Gompertz	128.94 ± 23.32	3.71 ± 0.99	0.09 ± 0.03	75%			
Von Bertalanffy	137.66 ± 31.11	0.84 ± 0.20	0.08 ± 0.03	75%			
Length of front flipper					45	47.2 ± 1.9	55.0
Logistic	53.11 ± 6.72	5.87 ± 1.56	0.12 ± 0.03	75%		(*n* = 8)	
Gompertz	58.02 ± 10.72	2.47 ± 0.51	0.08 ± 0.03	75%			
Von Bertalanffy	60.80 ± 13.45	0.62 ± 0.12	0.07 ± 0.03	75%			
Length of hind flipper					44	28.7 ± 0.9	32.0
Logistic	32.04 ± 3.34	6.48 ± 2.77	0.15 ± 0.04	66%		(*n* = 7)	
Gompertz	33.33 ± 4.52	2.84 ± 1.04	0.11 ± 0.04	66%			
Von Bertalanffy	33.95 ± 5.16	0.73 ± 0.26	0.09 ± 0.04	66%			
Skull (mm)							
Condylobasal length					61	253.9 ± 2.6	275.4
Logistic	269.48 ± 5.57	4.36 ± 0.87	0.17 ± 0.02	89%		(*n* = 14)	
Gompertz	273.19 ± 6.66	2.45 ± 0.44	0.14 ± 0.02	89%			
Von Bertalanffy	274.75 ± 7.16	0.68 ± 0.12	0.13 ± 0.02	89%			
Bizygomatic breadth					61	149.1 ± 2.0	158.9
Logistic	165.68 ± 7.37	3.83 ± 0.81	0.13 ± 0.02	84%		(*n* = 14)	
Gompertz	171.50 ± 9.98	2.01 ± 0.36	0.09 ± 0.02	84%			
Von Bertalanffy	174.22 ± 11.33	0.54 ± 0.09	0.09 ± 0.02	84%			
Mastoid breadth					59	137.5 ± 6.0	149.7
Logistic	153.18 ± 5.36	5.26 ± 1.06	0.15 ± 0.02	88%		(*n* = 14)	
Gompertz	158.22 ± 7.15	2.53 ± 0.43	0.11 ± 0.02	88%			
Von Bertalanffy	160.59 ± 8.09	0.67 ± 0.11	0.09 ± 0.02	88%			
Length of mandible[b]					60	191.5 ± 2.9	194.1
Logistic	192.14 ± 5.16	5.76 ± 1.32	0.17 ± 0.02	87%	*(50)*	(*n* = 13)	
	(190.06 ± 9.62)	*(1.13 ± 0.10)*	*(0.26 ± 0.05)*	*(86%)*			
Gompertz	195.96 ± 6.41	2.88 ± 0.58	0.13 ± 0.02	87%			
	(196.08 ± 12.54)	*(0.81 ± 0.05)*	*(0.20 ± 0.05)*	*(86%)*			
Von Bertalanffy	197.65 ± 7.01	0.77 ± 0.15	0.12 ± 0.02	87%			
	(198.85 ± 14.02)	*(0.24 ± 0.01)*	*(0.18 ± 0.05)*	*(86%)*			
Baculum (mm)							
Bacular length[b]					35	112.1 ± 6.4	139.3
Logistic	119.10 ± 2.96	743.85 ± 683.54	0.47 ± 0.06	86%	(40)	(*n* = 14)	
	(119.89 ± 4.89)	*(2.51 ± 0.28)*	*(0.42 ± 0.06)*	*(93%)*			
Gompertz	120.19 ± 3.32	111.26± 82.91	0.36 ± 0.05	85%			
	(124.19 ± 6.59)	*(1.35 ± 0.09)*	*(0.30 ± 0.05)*	*(93%)*			
Von Bertalanffy[c]	–	–	–	–			

R^2, 1 – residual SS/Total corrected SS (where SS is the sum of squares).

[a] Mean value for adults and maximum value is derived from Stewardson *et al.*, (200X*a*, *b*, *c*) and includes males ≥ 7 y 7 mo and unaged males > 200 cm.

[b] Estimated asymptotic size derived from chronological age given in round brackets and italics.

[c] The von Bertalanffy model for bacular length did not fit the data as well as the other two models; asymptotic size derived from this model was not considered to be reliable.

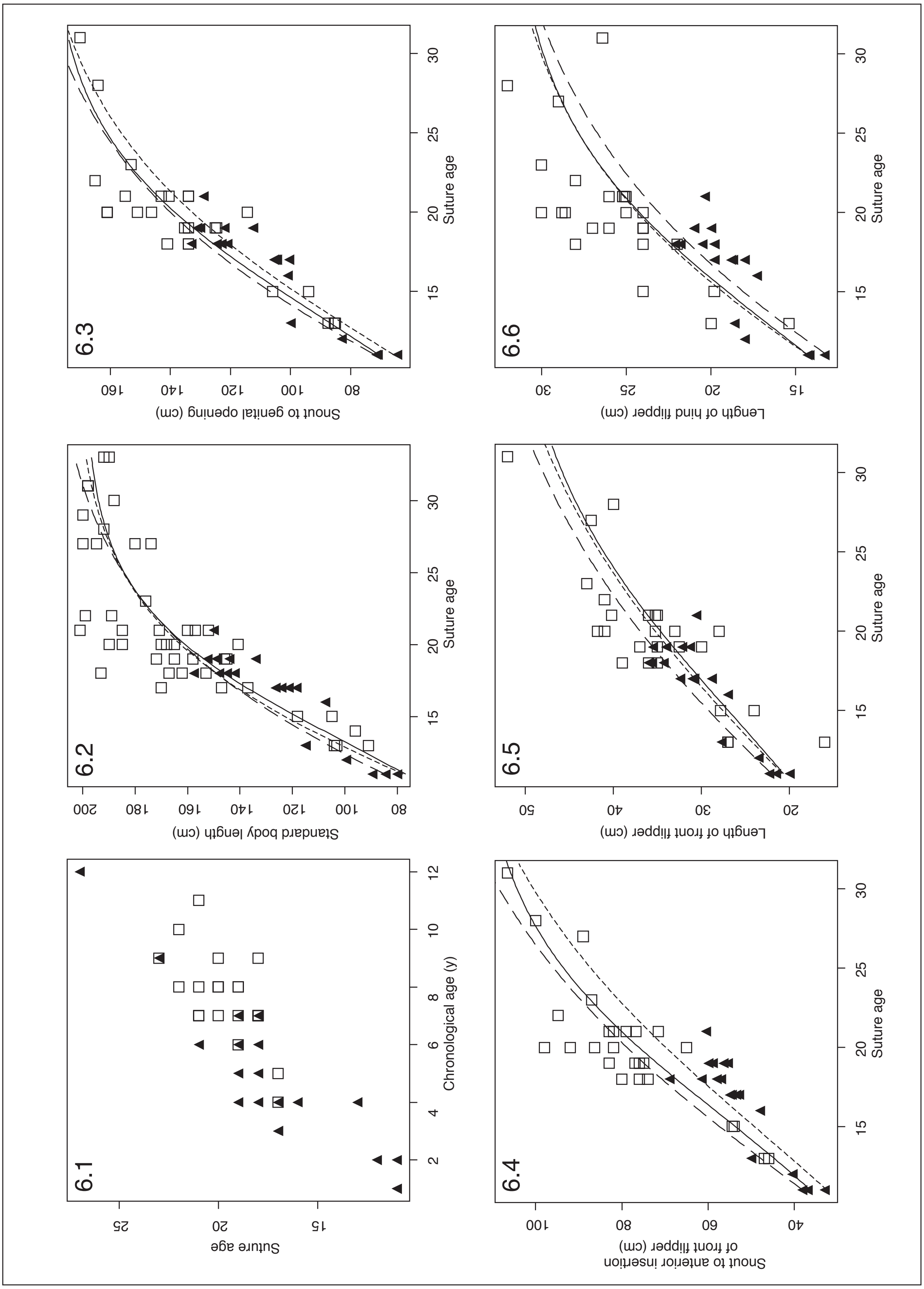

Fig. 6.1–6.6 Bivariate plot of: (1) suture age on chronological age (y) (*n* = 21 MCM known-age animals and *n* = 21 canine aged PEM animals); (2) Seal body length (cm) on suture age; (3) Tip of snout to genital opening (cm) on suture age; (4) Tip of snout to insertion of front flipper (cm) on suture age; (5) Length of front flipper (cm) on suture age; (6) Length of hind flipper (cm) on suture age.

Squares, canine aged animals. Solid triangles, known-age animals (animals tagged as pups). __ __ __ = von Bertalanffy growth model; _ _ _ _ = Gompertz growth model; __ = Logistic growth model.

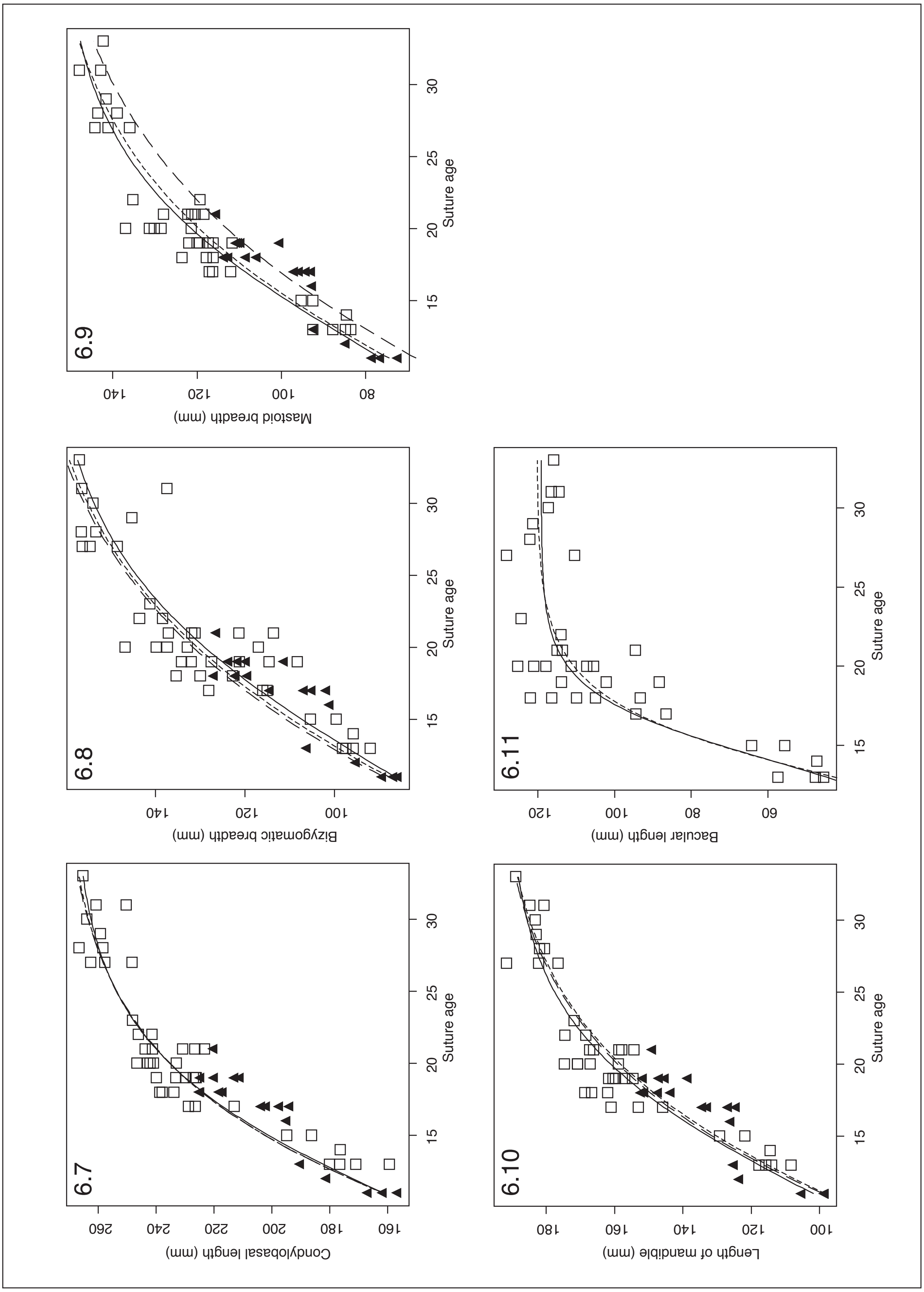

Fig. 6.7–6.11 Bivariate plot of: (7) condylobasal length (cm) on suture age; (8) Zygomatic breadth (cm) on suture age; (9) Mastoid breadth (cm) on suture age; (10) Length of mandible (cm) on suture age; (11) Bacular length (mm) on suture age. Squares, canine aged animals. Solid triangles, known-age animals (animals tagged as pups). __ __ __ = von Bertalanffy growth model; _ _ _ _ = Gompertz growth model; — = Logistic growth model.

DISCUSSION

Suture closure

Examination of suture age relative to SBL supported the sequence of FSC derived from chronological age, and suggested that: (i) full closure of the interparietal occurs before full closure of the coronal, and (ii) full closure of the maxillary occurs after full closure of the squamosal-jugal in some animals, i.e., basioccipito-basisphenoid, occipito-parietal, interparietal, coronal, squamosal-jugal and finally the maxillary.

With the exception of the squamosal-parietal, the sutures of the brain case (basioccipito-basisphenoid, occipito-parietal, coronal, interparietal) close before those of the face (squamosal-jugal; premaxillary-maxilla) (present study). As with other mammals, the brain case attains full size early in development (neural growth pattern) because early maturation of the brain case is essential for nervous control of the body (Moore, 1981).

The sequence of FSC reported by Rand (1949) based on male Cape fur seals of unknown chronological age was: basioccipito-basisphenoid, occipito-parietal, interparietal, coronal, squamosal-parietal, premaxillary-maxillary; interfrontal and basisphenoid-presphenoid (fully mature bulls, SBL *c.* 217 cm); and finally the internasal (i.e., old emaciated animals, SBL *c.* 223 cm). The maxillary was not examined. The sequence of FSC for the first 4 sutures was supported by the present study, and confirmed that certain sutures do not fully fuse until the animal is > 12 y (e.g., premaxillary-maxilla, maxillary, inter-frontal, basisphenoid-presphenoid and internasal).

In male *Zalophus californianus*, California sea lion, the sequence of PSC and FSC (n = 9 sutures) differed slightly from *A. p. pusillus*. The sequence of PSC was: basioccipito-basisphenoid, coronal/squamosal-parietal, occipito-parietal, interfrontal, interparietal, premaxillary-maxilla, basisphenoid-presphenoid and finally the maxillary, while the sequence of FSC was: basioccipito-basisphenoid, occipito-parietal, interparietal, squamosal-parietal, coronal, basisphenoid-presphenoid and finally the interfrontal/premaxillary-maxilla/maxillary, with all sutures fully closed by 15 y (n = 35 males, 1–15 y) (Orr & Schonewald, 1970).

In male *Callorhinus ursinus*, northern fur seal, the age at which the sutures begin to close and the length of time taken for sutures to fully close was slightly different than in *A. p. pusillus* (Scheffer & Wilke, 1953, present study). For example, the basioccipito-basisphenoid closes between 2 and 6 y; the occipito-parietal closes between 2 and 6 y; and the interparietal closes between 4 and 7 y (n = 121 males *C. ursinus*, 1–7 y). Other sutures were not examined.

Differences in growth rates/patterns, considerable individual variation between animals of similar age, and small sample size, would account for observed discrepancies within and between species.

Suture age as an indicator of chronological age

In male Cape fur seals, suture age can not be used as a reliable technique for estimating chronological age (present study).This is in agreement with comprehensive studies on humans (McKern, 1970; McKern & Stewart, 1957).

However, one of the sutures, the basioccipito-basisphenoid located at the base of the brain case, can be used independently as a 'very rough' indicator of age in male Cape fur seals (present study). The sequence of closure of the basioccipito-basisphenoid suture in Cape fur seals exhibited little variability, with complete fusion evident at 3 or 4 y. Examination of this suture reveals the following: (i) suture open = male ≤ 3 y old; (ii) suture fully closed = male 3–4 y or older and male has reached puberty[2].

Asymptotic size

As with other polygynous breeding pinnipeds which exhibit pronounce size dimorphism, full reproductive status (social maturity) is deferred until full size and competitive vigour are developed (Bartholomew, 1970; McLaren, 1993). Male Cape fur seals attain social maturity at 8–10 y (Stewardson *et al.*, 200X*a*). Although some males may grow to 220 cm, or more (Rand 1949), asymptotic size is estimated to be between 200 and 215 cm (present study).

Information on asymptotic size (Table 6.5) is advantageous for comparison among different species of pinnipeds because average size (including average adult size) may be more influenced by sampling biases, e.g., larger or smaller individuals may be over-represented in certain year/suture classes (McLaren, 1993). In the absence of an accurate method to determine the age of Cape fur seals > 13 y, asymptotic size estimated from suture age appears to be of practical value. Asymptotic size estimates derived from suture age and chronological age were found to be very similar, e.g., bacular length and mandibular length.

CONCLUSIONS

In this study we have demonstrated that in male Cape fur seals: (i) the sequence of PSC is different to the sequence of FSC; (ii) the age at which the sutures begin to close is different; (iii) the length of time taken for sutures to fully close is different; (iv) the sequence of FSC is basioccipito-basisphenoid, occipito-parietal, interparietal/coronal and finally the squamosal-jugal in males ≤ 12 y; (v) suture age is

[2] Male Cape fur seals reach puberty at 3 or 4 y (Stewardson *et al.*, 1998).

not a reliable indicator of chronological age; and (vi) the basioccipito-basisphenoid can be used independently as an indicator of age. Furthermore, we have estimated asymptotic size for 10 morphological measurements inferred from suture age, a useful statistic for future comparative studies.

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