The Growth of the Crania of Yezo Brown Bear*

By

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(With Plate II–IV and 10 text-figures)

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So far as the author is aware, almost nothing has been brought to light about the metric characters of the skull of the Yezo brown bear, *Ursus arctos yezoensis* LYDEKKER (Figure 3 and 4 in Plate II–IV), since the publication of the original description of Dr. LYDEKKER (1897) based on three specimens from Hokkaidô. The description seems rather incomplete in the absence of precise measurements.

The collection of Ursidae skulls in the Institute has been accumulated within the last few years including as the youngest specimen the skull of a five months old cub and many older ones whose sutures are fusing and almost disappearing with the extremely worn out teeth. In addition six adult specimens of the Japanese black bear (*Ursus japonicus* SCHLEGEL, 1857) from Nagano Prefecture, Honsyû (Figure 1 in Plate II–IV), four adult specimens representing the Saghalien brown bear (*Ursus arctos* LINNAEUS, 1758) (Figure 2 in Plate II–IV), were available through the kindness of Mr. S. SUGAWARA, Curator of the Government Museum of Saghalien, and Mr. S. ÔISHI in the Institute of Geology of this University. To Dr. T. INUKAI the author wishes to express here his heartiest gratitude for his kind guidance and unceasing encouragement during the course of the work.

The changing proportions in various parts of the mammalian skull throughout life have been studied by numerous authors; for instance, SCHMITT (1903) on dogs, RÖRIG (1904) on deer, SCHRÖTER (1923) on pigs, HINTON (1926) on Microtinae, CASTLE (1923) on rabbits and on horses, etc. Recently the problem has been more clearly elucidated by the analysis using differential growth function, $y=bx^k$, as demonstrated by HUXLEY (1932) explaining in various organisms the continuous change of growth trend, instead of showing the absolute

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values and indices, thus HERSH (1932 and 1934) was successful in his study on dogs and on titanotheres (an extinct mammal somewhat allied to rhinoceros) and GREEN (1932) on mice. In the case of titanotheres when the basilar length (x) and the zygomatic width (y) of each skull are logarithmically plotted, we can obtain a straight line which has a different slope inclination according to the various genera. In this case the slope of each line is denoted by the constant k of the power function $y=bx^k$, which is generally given for a line in the double logarithmic plotting, otherwise by means of the ordinary plotting the above measurements result in an exponential curve. The value of k for the genera of titanotheres for example is as follows: Palaeosyops, 1.35; Dolichorhinus, 1.19; Metarhinus, 1.48; Brontops, 1.20; Allops, 1.91; Menodus, 0.75, etc. The constant b possesses by no means a slight biological significance as it only indicates the value of y when x=1. On the other hand the value of k, growth coefficient, is peculiar for each group. When the same mesurements are made for thirty two races of dogs, the results are represented by five distinct lines. GREEN (1932) showed the above feature clearly in the analysis of skull measurements of two species and their F_1 and back-cross hybrids, obtaining a different slope of line for each group.

In the present studies the measurements of the dimensions were obtained in mm with MARTIN's beam compasses and calliper compasses using the technique employed by DUERST (1926).

1. *The zygomatic width / basilar length relation.*

Dimension: Basilar length. Distance from the apex of intermaxillaries to the inferior edge of foramen magnum (Figure 1, a). (maximum, 351.0; minimum, 164.6) (Basion-Prosthion)

Zygomatic width. Distance between the zygomatic processes of the squamosals (Figure 1, b). (maximum, 257.0; minimum, 106.2) (Zygion-Zygion)

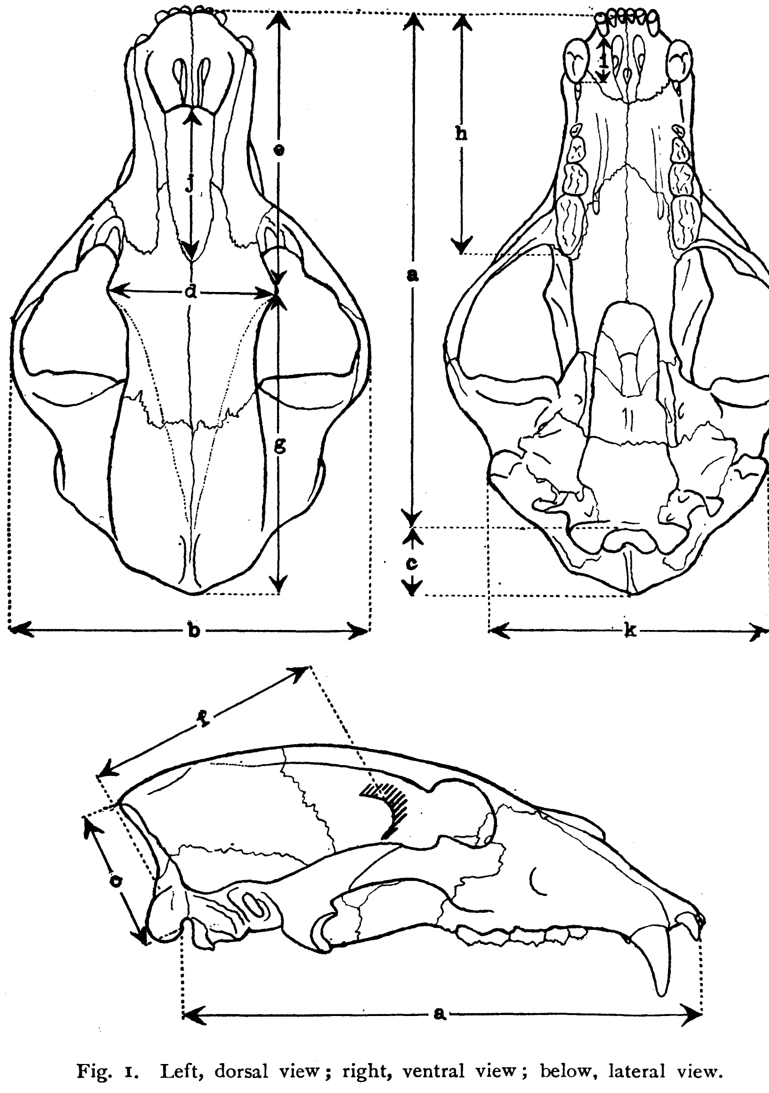


Fig. 1. Left, dorsal view; right, ventral view; below, lateral view.

a	Basilar length	g	Dorsal cranial length
b	Zygomatic width	h	Dental length
c	Height	i	Diastema
d	Width of frontal	j	Length of nasals
e	Preorbital length	k	Occipital breadth
f	Length of brain		

When these two dimensions are logarithmically plotted for all the available *yezoensis* specimens, 97 in number, the points distribute between two parallel lines which are drawn at the limiting boundary making a narrow band (Figure 2). The nature of the points which appear at the terminal part of the band outside of the main (Figure 2), has already been explained by HUXLEY (1932) and others, they occur frequently when too young and too old specimens are measured.

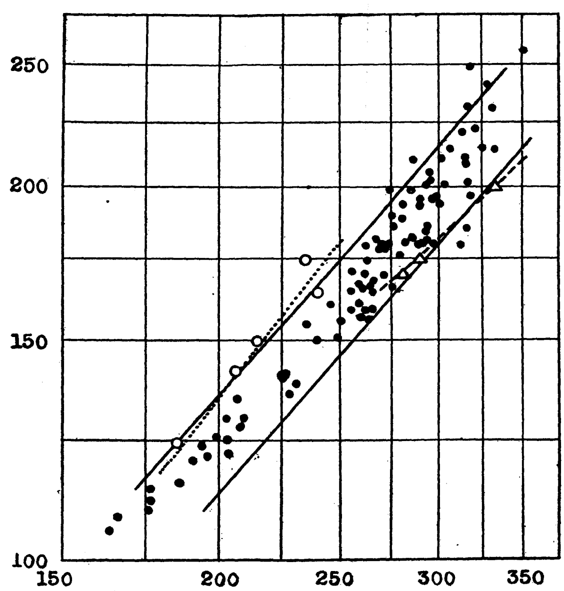


Fig. 2. Double logarithmic plot of the zygomatic width (y) against the basilar length of the skull (x). •, *yezoensis*; ○, *japonicus*; △, *arctos*.

The values of constants b and k are calculated and expressed by a straight line drawn in the middle of the band parallel to these. On this line most of the plotted points may aggregate. However, to avoid confusion, the line was not drawn in the present figure. The range of distribution of points is seen very clearly in the figure and also by the values given in parentheses in the table which is particularly useful for referrance in the case when there are many available specimens with individual variations.

y	x	*Ursus arctos* LINN.	
		k	b
Zygomatic width	Basilar length	0.932	0.894
Volume of cranial tetrahydron	Basilar length	3.025	$0.226 \cdot 10^{-4}$
Width of frontal	Preorbital length	1.230	$0.788 \cdot 10^{-1}$
Length of brain	Basilar length	0.214	24.900
Preorbital length	Dorsal cranial length	0.590	8.475
Dental length	Basilar length	0.978	0.547
Diastema	Basilar length	1.895	$0.533 \cdot 10^{-2}$
Length of nasals	Basilar length	2.492	$0.615 \cdot 10^{-4}$
Mastoid breadth	Height	1.905	0.030

Table 1. Values of b and k of the relative

As in the other mammals the basilar length of the bear increases as the eruption of the remaining incisors, canines, premolars and molars occurs. The building up of frontal sinuses and backward development of the lambdoidal crest proceeds with the age; the latter was particularly studied by MILLER (1912) in the European bear as the special character for the genus. The growth of the zygomatic breadth, or the greatest breadth of the bear skull, is chiefly effected by the extension of zygomatic arches through the strengthening of the muscles of mastication, as the braincase exerts little influence, as suggested by ALLEN (1910) in his work on the black bear of Labrador.

The *japonicus* and *arctos* skulls are similarly treated as in the above method (Figure 2). The slopes (k) for the three kinds of skulls are as follows: *yezoensis*, 1.151; *arctos*, 0.932; *japonicus*, 1.350. Though further materials are necessary for the determination of the exact value of constants for two forms, they are sufficient insofar as they serve just for comparison. When $k > 1$, as in the case of *japonicus*, the skull is progressively brachycephalic, that is, the zygomatic width is increasing more quickly than the basilar length; when $k < 1$, as in *arctos*, the skull is progressively dolichocephalic. In technical terms of differential growth, the increasing of a dimension of an organ at the same rate as other dimension, I. E., $k = 1$, is called isogonic. And if it is growing at a rapid or slow velocity as compared with the other dimension, $k > 1$ as in *japonicus*, or $k < 1$ as in *arctos*, it may be styled positive and negative heterogonic, respectively. The skull of *arctos* becomes narrowest and longest in proportion to the breadth as it grows, while in the *japonicus* skull the relation is reversed. The skull of *yezoensis* exhibits an intermediate character between the two. SWARTH (1911) described the same tendency as the peculiarities of an insular race among American black bear measuring the absolute dimension

Ursus arctos yezoensis LYD.			*Ursus japonicus* SCHL.	
k	b		k	b
1.151	0.278	(0.305~0.252)	1.350	0.104
3.050	$0.236 \cdot 10^{-4}$	($0.271 \cdot 10^{-4}$ ~ $0.206 \cdot 10^{-4}$)	3.407	$0.350 \cdot 10^{-5}$
1.228	0.187	(0.214~0.165)	1.656	$0.402 \cdot 10^{1}$
0.602	4.350	(4.830~3.940)	0.797	1.435
0.747	3.500	(3.785~3.240)	0.662	4 090
0.595	4.770	(5.060~4.470)	0.557	4.976
1.640	$0.233 \cdot 10^{-2}$	($0.281 \cdot 10^{-2}$ ~ $0.195 \cdot 10^{-2}$)	0.145	8.707
1.051	0.215	(0.238~0.198)	0.191	18.617
1.420	0.269	(0.308~0.237)	0.922	2.643

growth function $y = bx^k$ for the three forms.

and the length-breadth index, the latter of which is a fundamental one for mammalian systematics, corresponding to the zygomatic width / basilar length relation above dealt with.

It is an interesting fact that the plotted points of 4 male skulls always distribute in the lower part of the band in the figure, whereas these of 5 female ones in the upper. Further research in detail is desired to secure full analysis in this point.

2. *The volume of cranial tetrahydron / basilar length relation.*

Dimensions: Height is measured from lower border of foramen magnum to occipital crest (Figure 1, c). (maximum, 119.2; minimum, 53.0)

(Basion-Opisthocranion)

Volume of cranial tetrahydron, which is governed by basilar length, zygomatic width and height, is calculated in cc by the following formulae, namely,

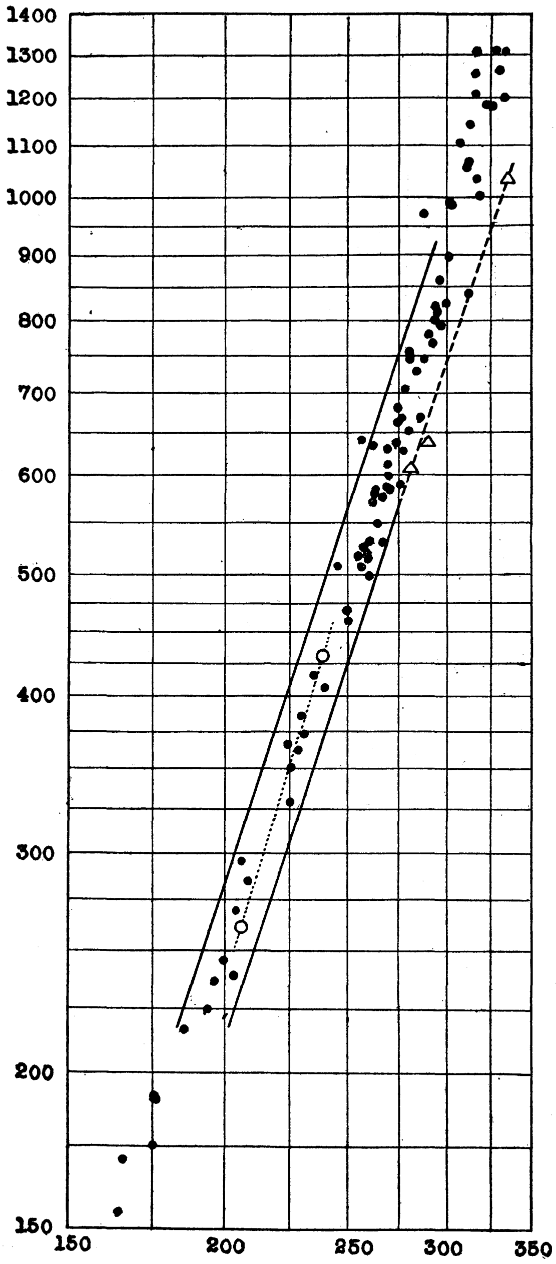
$$\frac{\text{Basilar length} \cdot \text{Zygomatic width} \cdot \text{Height}}{6}$$

(maximum, 1792.1; minimum, 155.3)

Available number of specimens was in *yezoensis* 92, in *arctos* 3 and in *japonicus* 5 respectively.

On a double logarithmic plot (Figure 3) the volume of cranial tetrahydron (y) is plotted against the basilar length (x). The points of each *yezoensis* specimens fall in a narrow band between two parallel lines, except at the upper part of the figure.

Table I shows again that the value of k exceeds 3 in every species. The rate of positively heterogonic growth in this case is the highest among the relations treated in the present paper. The special character of the insular race is here again expressed by the shortening of basilar length, in the meaning of relative growth, as is shown in the table by the value of k; the *japonicus* has



3.407 as k which indicates a massive growth of the cranium, the *yezoensis* 3.050 is medium type while *arctos* 3.025 is the slenderest.

3. *The width of frontal / preorbital length relation.*

Dimensions: The width of frontal. Distance across post-orbital processes (Figure 1, d). (maximum, 144.5; minimum, 56.4) (Ectorbital-Ectorbital)
Preorbital length. Length from postorbital processes to apex of intermaxillaries in projection (Figure 1, e). (maximum, 199.7; minimum, 99.0) (Ectorbital-Prosthion)

Available number of specimens: *yezoensis*, 130; *arctos*, 3; *japonicus*, 5.

When the width of frontal (x) and the preorbital length (y) of the different individuals are logarithmically plotted, the points distribute in a narrow band, (Figure 4) with the exception of the higher values.

The results obtained in this relation are also presented in Table I.

As already stated by ALLEN (1910) and SCHÄFF (1889) the lateral expansion of frontal is remarkable in Ursidae. In every form it increases more rapidly than the preorbital length, which repre-

Fig. 3. Double logarithmic plot of the volume of cranial tetrahydron (y) against the basilar length of the skull (x). •, *yezoensis*; o, *japonicus*; △, *arctos*.

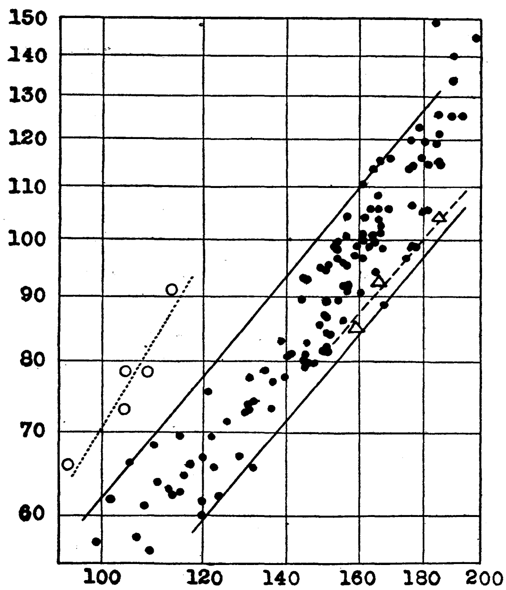


Fig. 4. Double logarithmic plot of the width of frontal (y) against the preorbital length (x).
•, *yezoensis*; o, *japonicus*; △, *arctos*.

sents the foreward extension of the facial part of the cranium, the rate being higher than 1; this is positively heterogonic. The *japonicus*, which is recognized as an insular form, possesses the broadest face on the upper part, and the *yezoensis* the next broadest while the *arctos* the narrowest. In technical terms of index calculation they are called progressively brachyoprosopic. The fact that the *japonicus* has a shorter muzzle than that of brown bear agrees with the statement of LYDEKKER (1922).

4. *The length of brain / basilar length relation.*

Dimensions: The length of brain. The length from dorso-caudal border of foramen magnum to cribriform plate of ethmoid was measured using an iron stick with a diameter of 6 mm as suggested by DUERST (1926) (Figure 1, f). (maximum, 159.0; minimum, 99.5) (Opsthion–X)

When the length of brain (y) is plotted against the basilar length of the cranium (x) logarithmically, as in Figure 5, all the points of measurements for the *yezoensis* specimens fall in a narrow band. The value of exponent k was calculated as shown in Table I.

Available number of specimens: *yezoensis*, 87; *arctos*, 3; *japonicus*, 4.

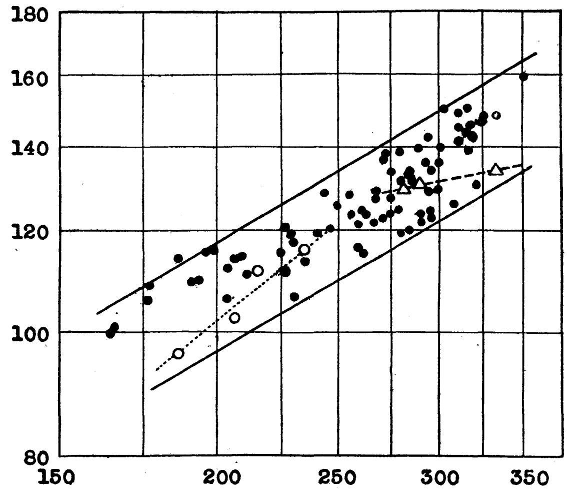


Fig. 5. Double logarithmic plot of the length of brain (y) against the basilar length (x) of the skull. •, *yezoensis*; o, *japonicus*; △, *arctos*.

The brain growth is found to be very slow or negatively heterogonic as compared with the basilar length. This is contrary to statements by many authors on various mammals and to SCHÄFF (1889) who working on Russian brown bears said there is no growth of the brain. The rate of the growth of the brain is the highest in *japonicus*, medium in *yezoensis* and the lowest in *arctos*.

5. *The preorbital length / dorsal cranial length relation.*

Dimension: Dorsal cranial length. Length from ectorbital process to occipital crest in projection (Figure 1, g). (maximum, 228.9; minimum, 92.5) (Opisthocranion-Ectorbital)

Available number of specimens: *yezoensis*, 128; *arctos*, 3; *japonicus*, 4.

The preorbital length (y) and the dorsal cranial length (x) of the *yezoensis* skull fall within a narrow band when they are plotted in conformity with the power function (Figure 6).

Relative growth coefficients are given in Table I. These negative heterogonic values of k throughout the three forms indicate that the growth of the face is progressively slow as compared with that of the hind part of the skull which is chiefly affected by the development of the frontal sinuses, bulbous nasal region and the lambdoidal crest rather than by growth of the brain. The term of index explanation styles it progressively dolichoprosopic. From the ecological

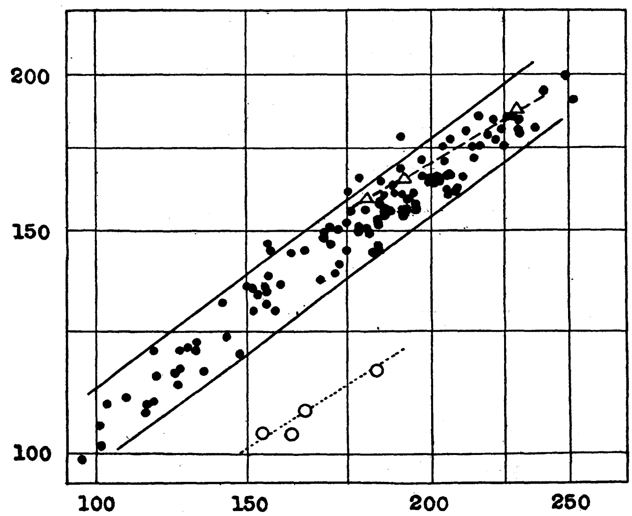


Fig. 6. Double logarithmic plot of the preorbital length (y) against the dorsal cranial length of the skull (x). •, *yezoensis*; o, *japonicus*; △, *arctos*.

viewpoints the active growth in the inner nasal region is quite natural as the power of scent of bears is the acutest of all their senses as FLOWER and LYDEKKER (1891) and others have explained. Comparison of the slope values between the three species reveals a condition which differs a little from the other relations of the skull, *japonicus* not falling between the other two forms in this respect.

6. *The dental length / basilar length relation.*

Dimension: The dental length. Distance from the middle of line connecting posterior margin of alveolus of last molar to apex of intermaxillaries (Figure 1, h). (maximum, 156.0; minimum, 88.0) (Prosthion-Postdental)

Available number of specimens: *yezoensis*, 96; *arctos* and *japonicus* 3, respectively.

A graph very similar to the above figures is obtained by plotting the dental length (y) against the basilar length (x) of the skull (Figure 7).

Growth coefficients are shown in Table I. A rapid growth in dental length follows the eruption of the permanent dentition, namely the third incisor, canine, premolars and second molar, but it occurs rather slowly as compared with that of the basilar length. From the value of exponent they are all negatively heterogonic or should be called progressively brachyodont as expressed in terms

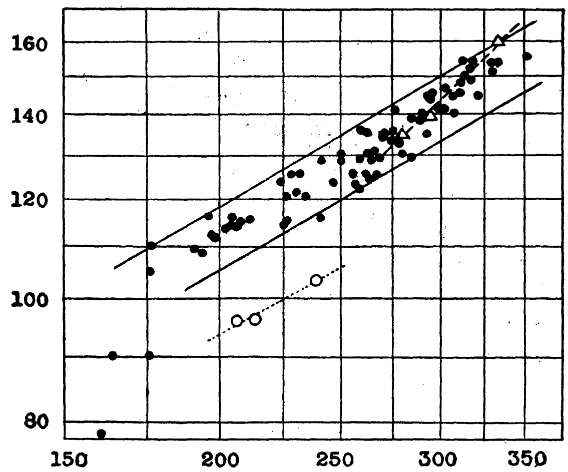


Fig. 7. Double logarithmic plot of the dental length (y) against the basilar length of the skull (x). o, *yezoensis*; •, *japonicus*; △, *arctos*.

of index treatment. The insular peculiarity is here again emphasized in the relation of k: *arctos*, the highest; *yezoensis*, the middle; *japonicus*, the lowest. The undermost point in the figure is not included in the limit of the band of later stages in which an abrupt increase of permanent teeth takes place.

7. *The diastema / basilar length relation.*

Dimension: Diastema. Length from the posterior border of the third incisor to the anterior of the first premolars (Figure 1, i). (maximum, 32.0; minimum, 8.4) (Incisivocaudal-Premolar)

Available number of specimens: *yezoensis*, 100; *arctos*, 3; *japonicus*, 3.

In Figure 8 the values of the diastema (y) are shown plotted against the basilar length (x), in conformity with the relative growth function. The specimens of each species fall within a narrow band (see also Table I).

The progressive shortening of the skull is peculiar for the insular race, occuring most conspicuously in *japonicus*, the growth rate in this part being inferior as compared with *yezoensis* which stands again lower in this respect than *arctos*. The same break as in the preceding relation is found at the lower part of the figure due to the canine eruption.

8. *The length of nasals / basilar length relation.*

Dimension: Length of nasals. Length of nasal bone in middle sutures

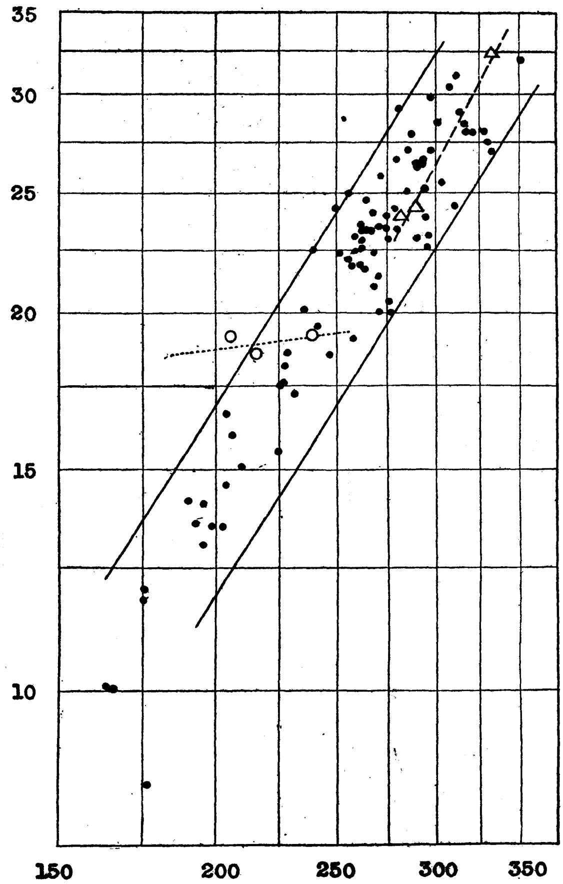


Fig. 8. Double logarithmic plot of the diastema (y) against the basilar length of the skull (x). ●, *yezoensis*; ○, *japonicus*; △, *arctos*.

(Figure 1, j). (maximum, 107.9; minimum, 42.2) (Nasion-Rhinion)

Available number of specimens: *yezoensis*, 96; *arctos*, 3; *japonicus*, 3.

When the length of nasals (y) is plotted against the basilar length (x) of the skull for all the specimens, the points distribute in a narrow band (Figure 9).

A glance at Table I shows that the rate of growth of nasal bone in *yezoensis* is nearly isogonic, that is, this extension keeps pace with that of basilar length, while in *japonicus* it is negatively heterogonic and in *arctos* positively heterogonic. The progressive shortening of the face expressed in *japonicus* agrees with the fact which NOACK (1903) explained.

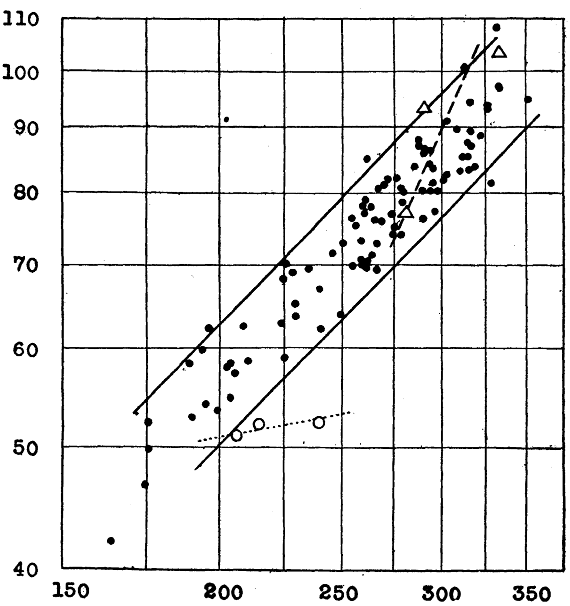


Fig. 9. Double logarithmic plot of the length of nasals (y) against the basilar length of the skull (x). ●, *yezoensis*; o, *japonicus*; △, *arctos*.

9. *The occipital breadth / height relation.*

Dimension: The occipital breadth. Distance between mastoid processes (Figure 1, k). (maximum, 207.9; minimum, 75.3) (Otion-Otion)

Available number of specimens: *yezoensis*, 91; *arctos*, 4; *japonicus*, 2.

When the two dimensions are logarithmically plotted, the points for the *yezoensis* specimens fall within a narrow band which conforms with the relative growth function (Figure 10).

The active lateral extension of mastoid processes has been stated as the special feature of the genus by ALLEN (1910). The increasing in breadth is most intense in *arctos*, making the cranium progressively low and broad at the hind part, while it is less expressed in *japonicus*. *Yezoensis* is intermediate in this respect.

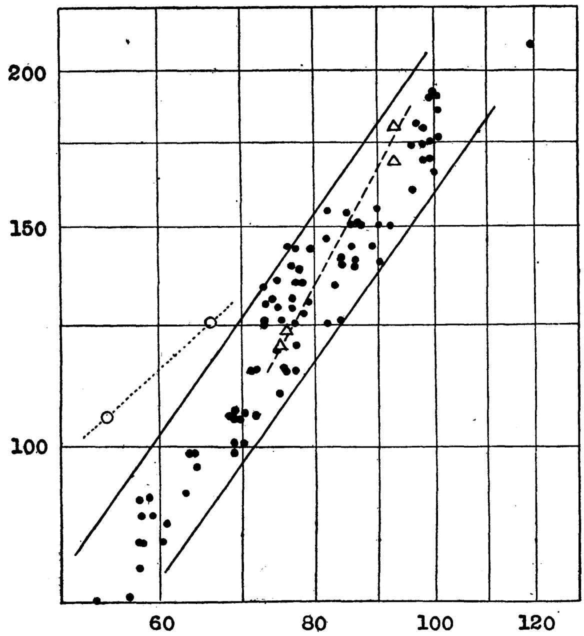


Fig. 10. Double logarithmic plot of the occipital breadth (y) against the height of the skull (x). ●, *yezoensis*, ○, *japonicus*; △, *arctos*.

Summary

The characteristic features of growth of the bear skull with the advance of age including individuals from the youngest whose milk second incisor still remains, to the oldest whose sutures are almost disappearing, are (1) the rapid extension of zygomatic arches because of the growth of the muscles seizing and masticating food, (2) the expansion of frontal bone from development of frontal sinuses, (3) the comparatively slight growth of brain-case, (4) the development of the nasal region resulting from growth of the organs of smell and respiration and lastly, the elongation of jaws for the eruption of the remaining permanent dentition.

The author is of the opinion, as are many other authors, that the Japanese black bear originates from a type other than the Yezo and Saghalien brown bear which originates from the holarctic. From the mathematical point of view the Yezo brown bear is closely allied to the Eurasiatic brown bear, but it has a distinct local variety. When mathematically analysed by the differential growth function, $y = bx^k$, the growth coefficient k of Yezo brown bear, in eight of

the nine dimensions, exhibits an intermediate value between those of the other two species. The Japanese black bear is particularized by its dwarfness as compared with the other two.

The progressive shortening or inferiority in forward and backward growth observed in *japonicus* and *yezoensis* is recognized as an insular peculiarity as compared with *arctos*. This cranial character is specially exaggerated in *japonicus*.

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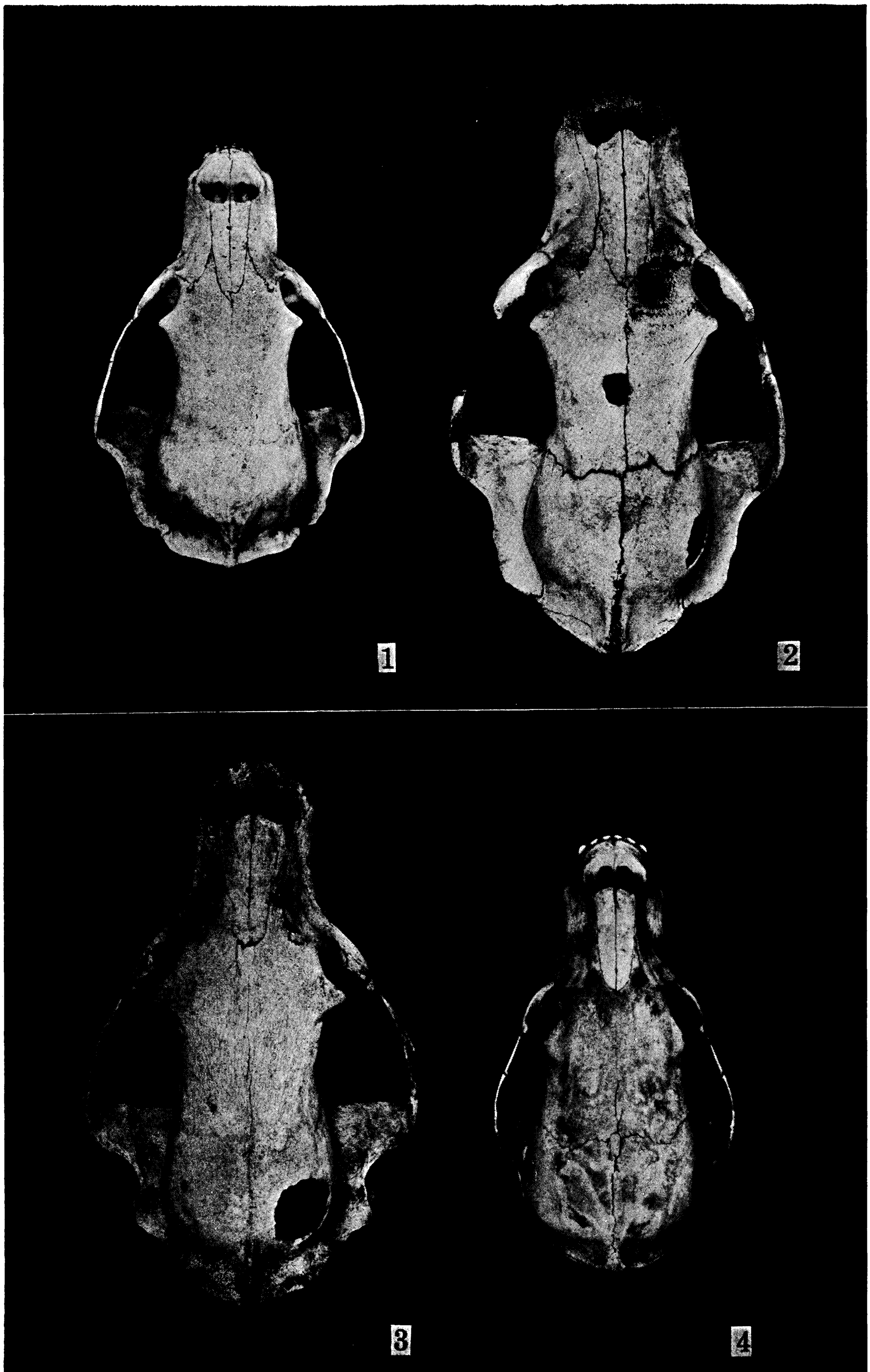
Explanation of Plates

Plate I Dorsal views, 1 : 0.29.

Plate II Ventral views, 1 : 0.31.

Plate III Lateral views, 1 : 0.30.

1. *Ursus japonicus* SCHLEGEL, 1857; no. J-4; adult female; Mount Kamanasi, Nagano Prefecture.
2. *Ursus arctos* LINNAEUS, 1758; no. 104; adult female; Saghalien.
3. *Ursus arctos yezoensis* LYDEKKER, 1897; no. 20; adult female; Mukawa, Hidaka Province, Hokkaidô.
4. *Ursus arctos yezoensis* LYDEKKER, 1897; no. 86; young female; Isikari Province, Hokkaidô.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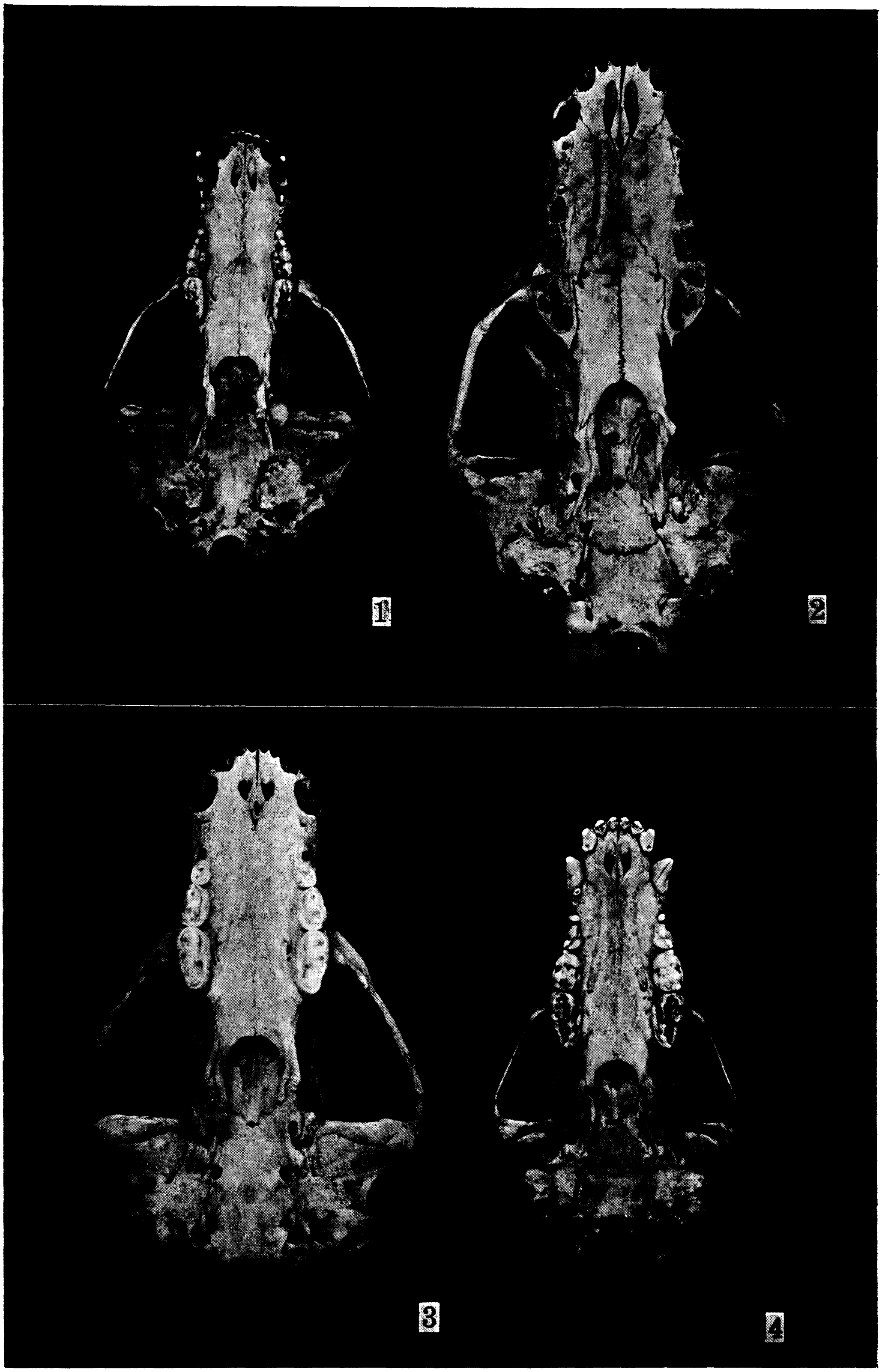
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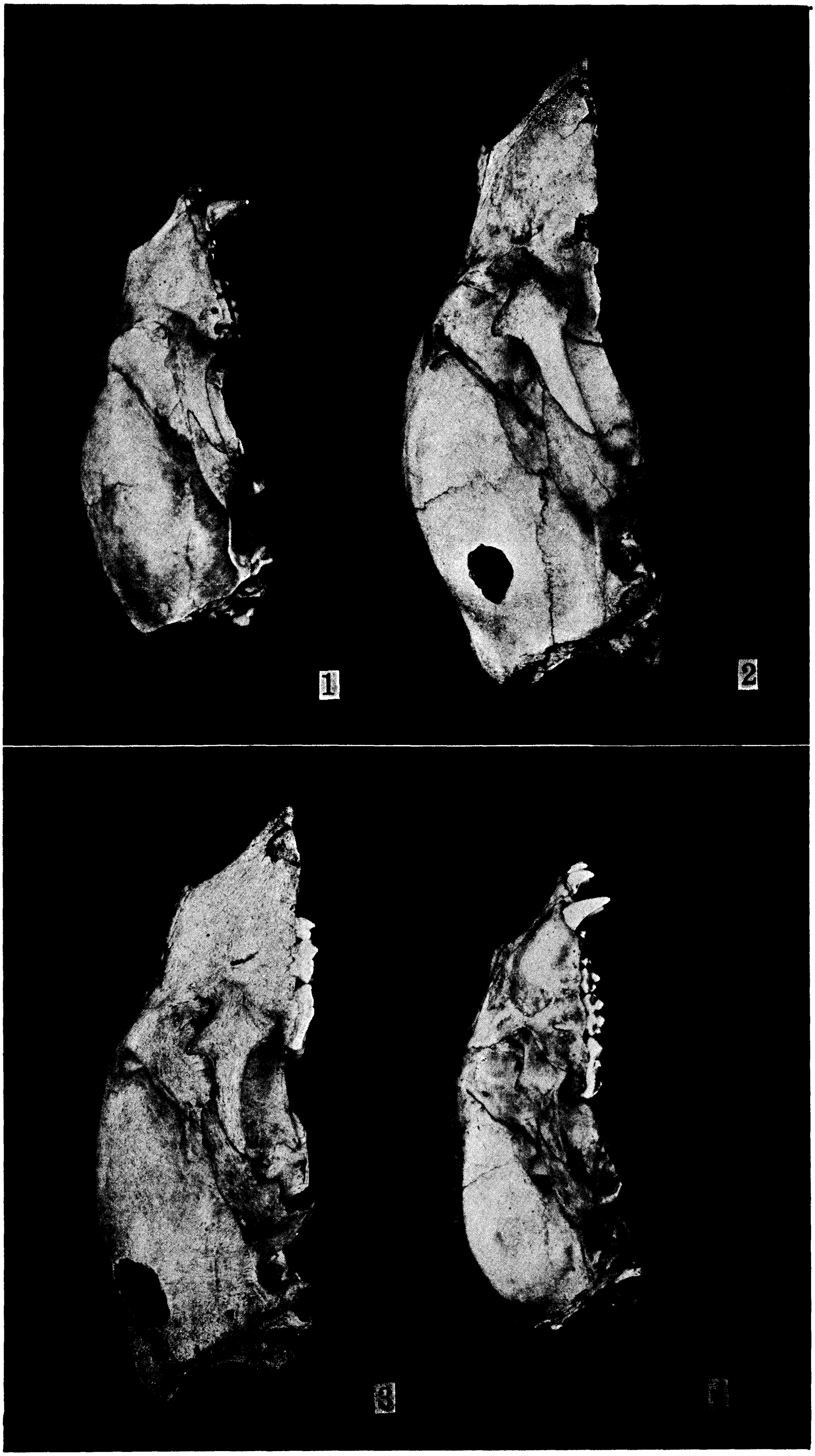
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